| |
|---|
| AD NUMBER |
| AD888984 |
| NEW LIMITATION CHANGE |
| TO<br>Approved for public release, distribution unlimited |
| FROM<br>Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; MAR 1971. Other requests shall be referred to Air Force Armament Lab., Eglin AFB, FL. |
| AUTHORITY |
| USADTC ltr 14 Mar 1979 |

AFATL-TR-71-32

# TEST AND EVALUATION OF MAGNUS ROTORS AND OTHER BODIES, FLIGHT DYNAMICS DATA REDUCTION AND ANALYSIS

DEPARTMENT OF AEROSPACE AND MECHANICAL ENGINEERING
UNIVERSITY OF NOTRE DAME

TECHNICAL REPORT AFATL-TR-71-32

MARCH 1971





AIR FORCE ARMAMENT LABORATORY

AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE

EGLIN AIR FORCE BASE, FLORIDA

54

# Test And Evaluation Of Magnus Rotors And Other Bodies, Flight Dynamics Data Reduction And Analysis

Dr. John D. Nicolaides
Dr. Charles W. Ingram

Details of illustrations in this document may be better studied on microfiche

Distribution limited to U. S. Government agencies only; this report documents tests and evaluation of military munitions; distribution limitation applied March 1971. Other requests for this document must be referred to the Air Force Armament Laboratory (DLRA), Eglin Air Force Base, Florida 32542.

# FOREWORD

This report documents research conducted during the period January 15, 1970 through January 14, 1971 by the Department of Aerospace and Mechanical Engineering, University of Notre Dame, Notre Dame, Indiana 46556, under Contract F08635-70-C-0033 with the Air Force Armament Laboratory, Eglin Air Force Base, Florida. Dr. Mark O. Glasgow (DLRA) was program monitor for the Armament Laboratory.

This report has been reviewed and is approved.

Charles K. Arpke

CHARLES K. ARPKE, Lt. Colonel, USAF
Chief, Technology Division

LIST OF FIGURES (CONCLUDED)

## TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONCLUDED)

## SECTION I

## BOMBLET MUNITION DELIVERY BY PARAFOIL

### INTRODUCTION

The Parafoil[a] is a true flying wing (Figure 1) based on a unique kite design discovered by D. Jalbert. Made entirely of low porosity nylon cloth, it has no rigid members but is composed of numerous cells which give it a unique rigid shape. It has an upper and a lower surface and an airfoil section, and the leading edge is open to permit inflation by ram air pressure.

The parafoil can be packaged and deployed in a manner similar to a conventional parachute. The suspension lines are attached to pennants distributed along the bottom surface. These pennants serve three purposes:

(1) To distribute the aerodynamic forces to the suspension lines

(2) To partially channel the flow into a two-dimensional flow pattern which reduces tip losses and improves the aerodynamic efficiency

(3) To provide side area which aids in obtaining directional flight stability.

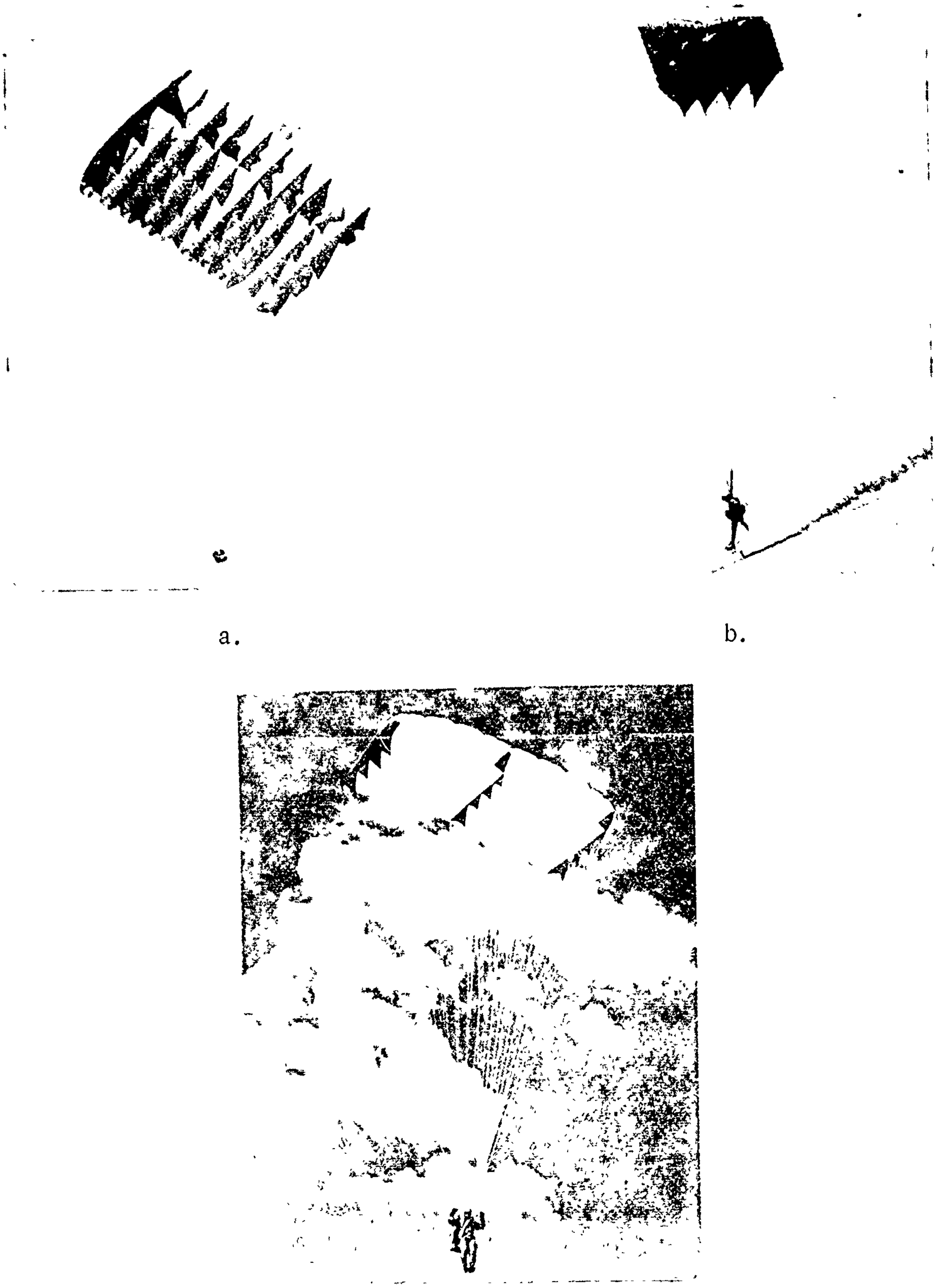
The term Parafoil, which denotes the combination of parachute and airfoil, was selected to describe various redesigns of the original Jalbert kite.[1,2]

The first studies of the Parafoil by contractor concentrated on wind tunnel tests of small models where the smoke flow could be studied and the various aerodynamic coefficients measured. Concurrent with these wind tunnel tests, various tethered and gliding flight tests were carried out on numerous Parafoil designs.[1-5]

Following these early wind tunnel and free-flight tests, Parafoils and Parafoil design and performance criteria were furnished to various organizations for test and evaluation against potential applications such as cargo delivery,[6] sounding rocket payload recovery,[7] tethered flight,[8] and manned flight. A summary of aerodynamic data on the Parafoil follows.

---

[a]The Parafoil is a design and development of Dr. John D. Nicolaides (patent pending) and is based on the multi-cell ram airfoil (Patent 3285546) held by SRRC, Inc., Florida.



a. b. c.

Figure 1. The Parafoil

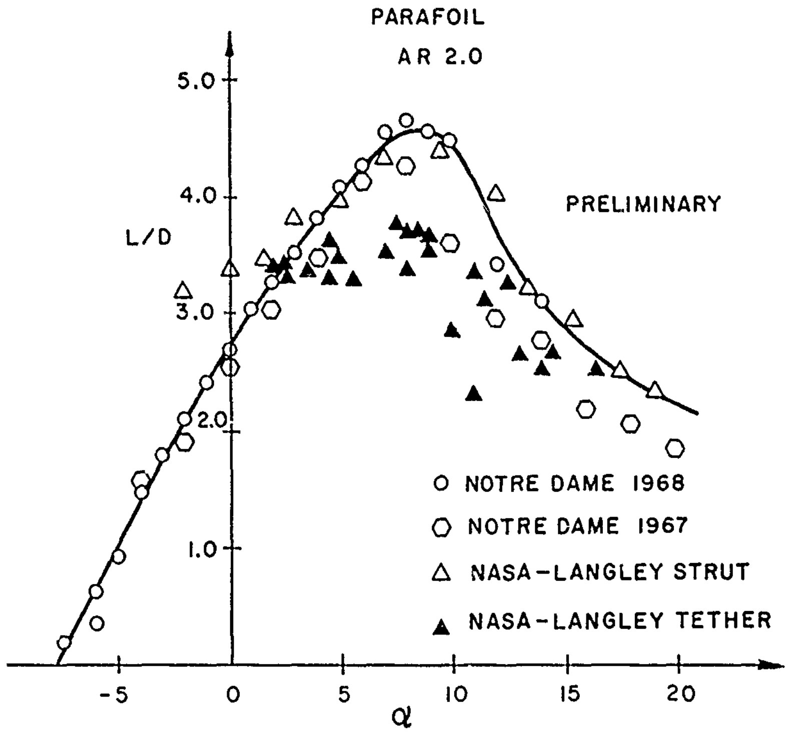



Figure 2. Lift-to-Drag as Function of Angle of Attack (AR = 2).

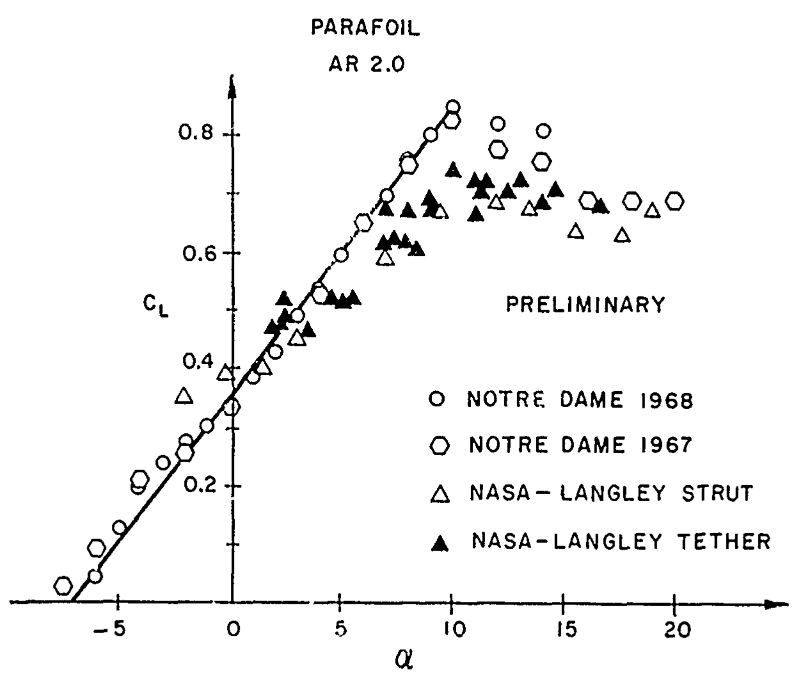



Figure 3. Coefficient of Lift as Function of Angle of Attack (AR=2).

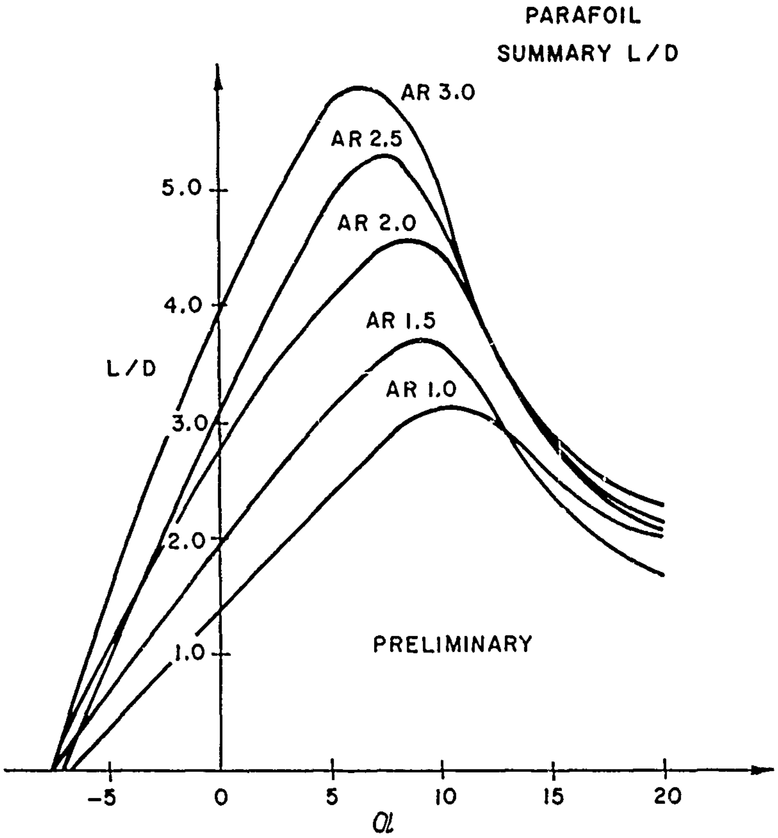



Figure 4. Summary Lift-to-Drag as Function of Angle of Attack.

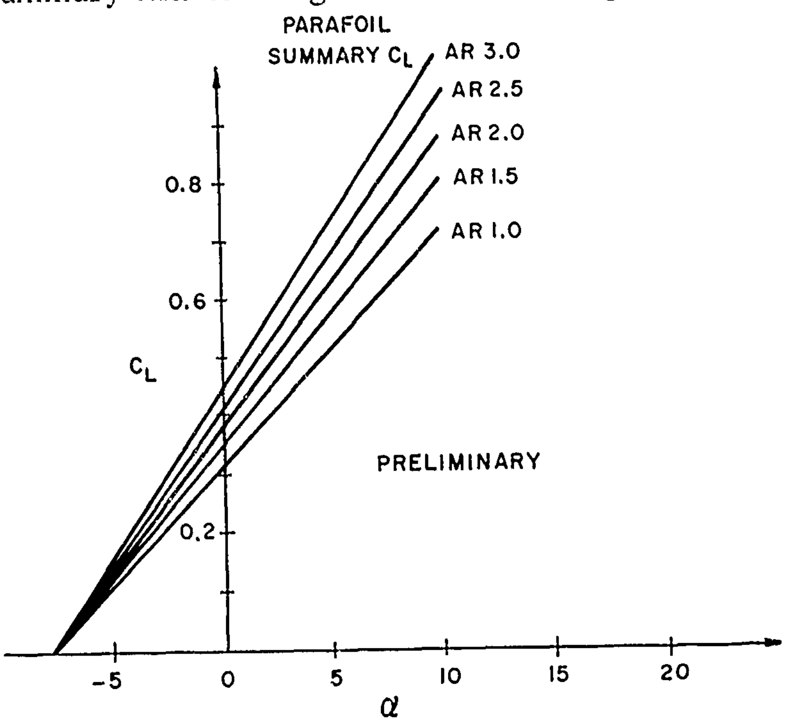



Figure 5. Summary Coefficient of Lift as Function of Angle of Attack.

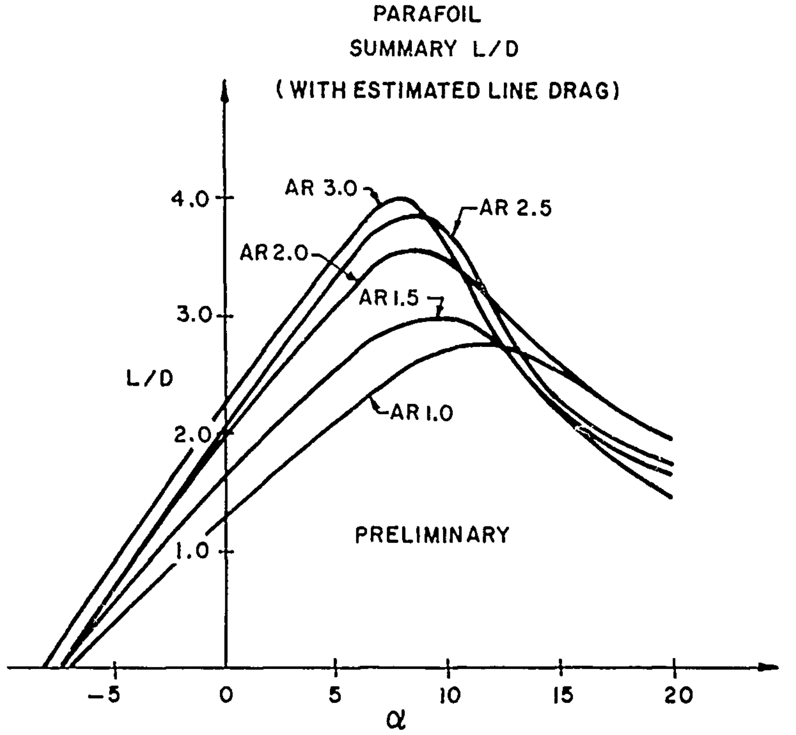



Figure 6. Summary Lift-to-Drag (With Estimated Line Drag Effects Included) As Function of Angle of Attack.

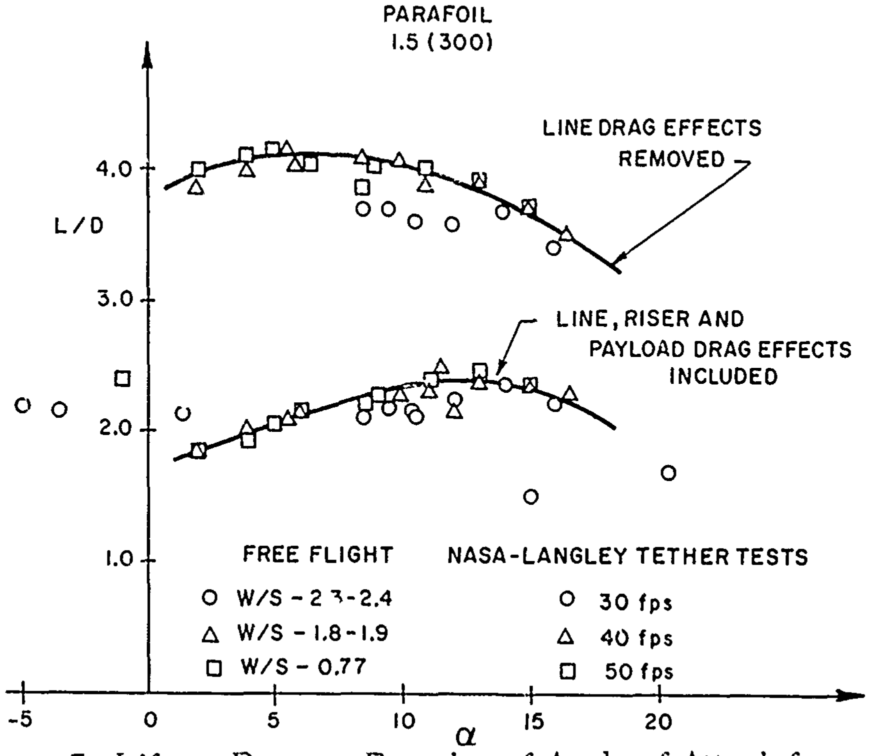



Figure 7. Lift-to-Drag as Function of Angle of Attack for AR 1.5 Cargo Delivery Parafoil.

## WIND TUNNEL TESTS

From the original Parafoil studies in 1964 until the present, wind tunnel tests of various Parafoil designs have been carried out. The Air Force has sponsored contractor in wind tunnel tests on Parafoil designs having aspect ratios (AR) of 1.0, 1.5, 2.0, 2.5, and 3.0. The rigid model for these tests had a chord of five inches, cloth upper and lower surfaces and rigid flares but no suspension lines.(9)

The Air Force has also sponsored contractor in a full-scale wind tunnel program with NASA-Langley. The 30 x 60-foot tunnel was used to test Parafoils ND 1.0 (147), ND 1.5 (147), ND 2.0 (147), ND 2.5 (147), and ND 3.0 (147), where the latter Parafoil designation, for example, indicates a Notre Dame Parafoil of aspect ratio 3 with a wing area of 147 square feet. Also an addition ND 3.0 (147) unit was progressively cut off to yield additional small models of aspect ratios 2.5, 2.0, 1.5, and 1.0. These Parafoils were tested in the freely tethered and the strut supported modes.(9)

Figures 2 and 3 present lift-to-drag[b] data and coefficient of lift data as functions of angle of attack for the AR = 2.0 units. Figures 4 and 5 present summary curves for the lift-to-drag[b] data and coefficient of lift[c] data as functions of angle of attack for the various aspect ratios. Figure 6 provides summary data which includes line drag based on 0.94-inch-diameter (about 400-pound) suspension lines and a cascade rigging technique. Wind tunnel data acquired on the 300-foot(2) AR 1.5 Parafoil is shown in Figure 7. The data presented is for particular Parafoil designs and does not necessarily represent an optimum airfoil section, planform, flare, or aspect ratio design.

## FREE-FLIGHT TESTS

Numerous free-flight tests of various Parafoil designs have been carried out.(10) Two testing techniques, (1) towed ascending flight where the inflated Parafoil is towed aloft and then released and (2) deployment of the Parafoil from an aircraft, have been utilized.

Free-flight lift-to-drag ratio data on the 300-foot(2) AR 1.5 Parafoil being used in the cargo delivery application is shown in Figure 7. Free-flight lift-to-drag ratios obtained on Parafoil ND 1.8 (360) are shown in Figure 8. This data was obtained by using the trailing smoke technique,

---

[b]NASA-Langley test data plotted after removing line drag effects.

[c]A common zero lift point was used.

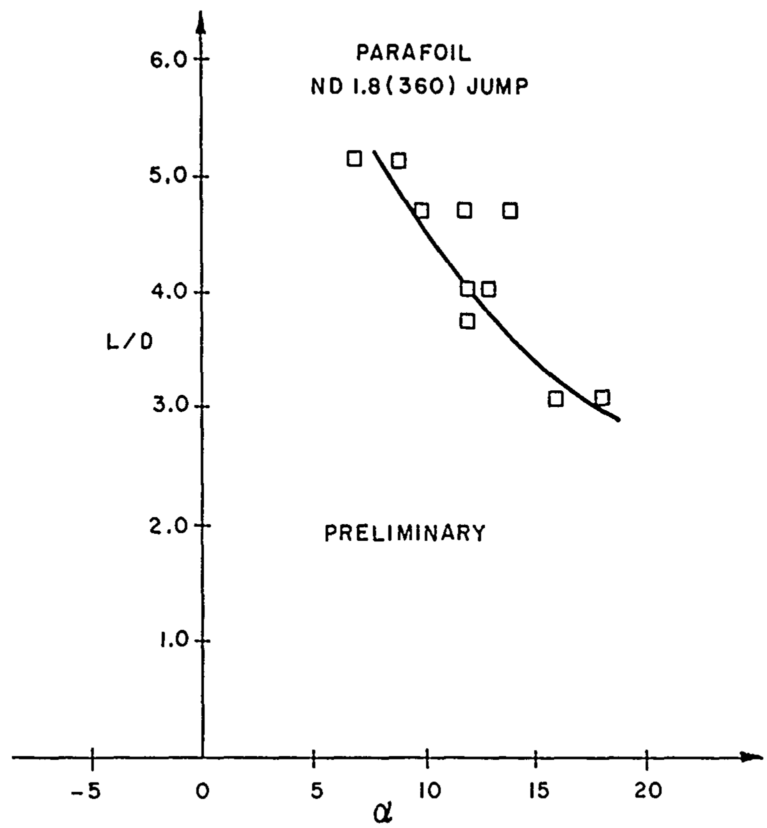



Figure 8. Lift-to-Drag as Function of Angle of Attack for ND 1.8 (360) Parafoil.

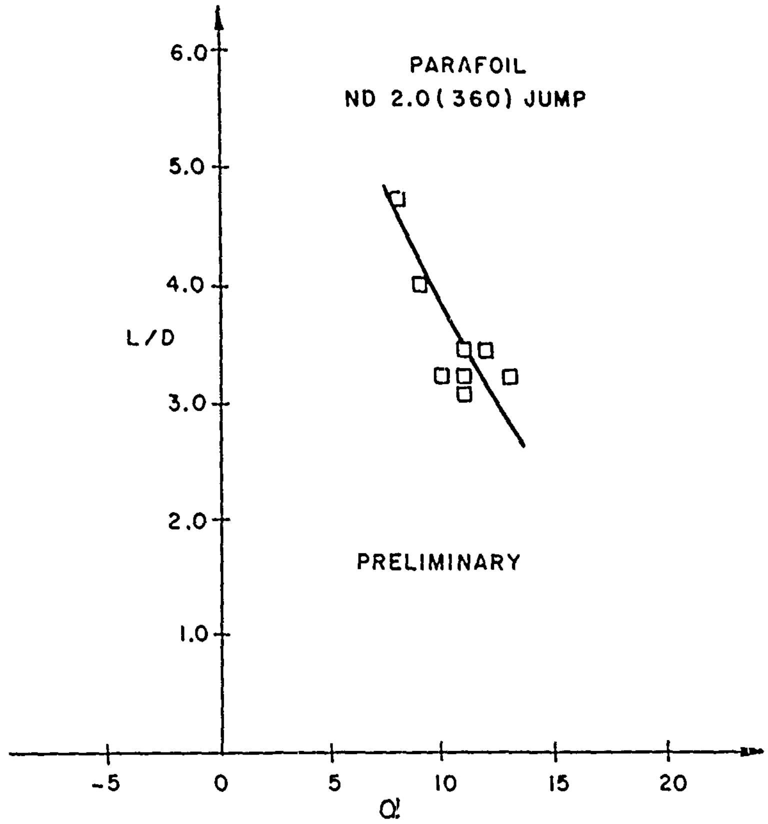



Figure 9. Lift-to-Drag as Function of Angle of Attack for ND 2.0 (360) Parafoil.

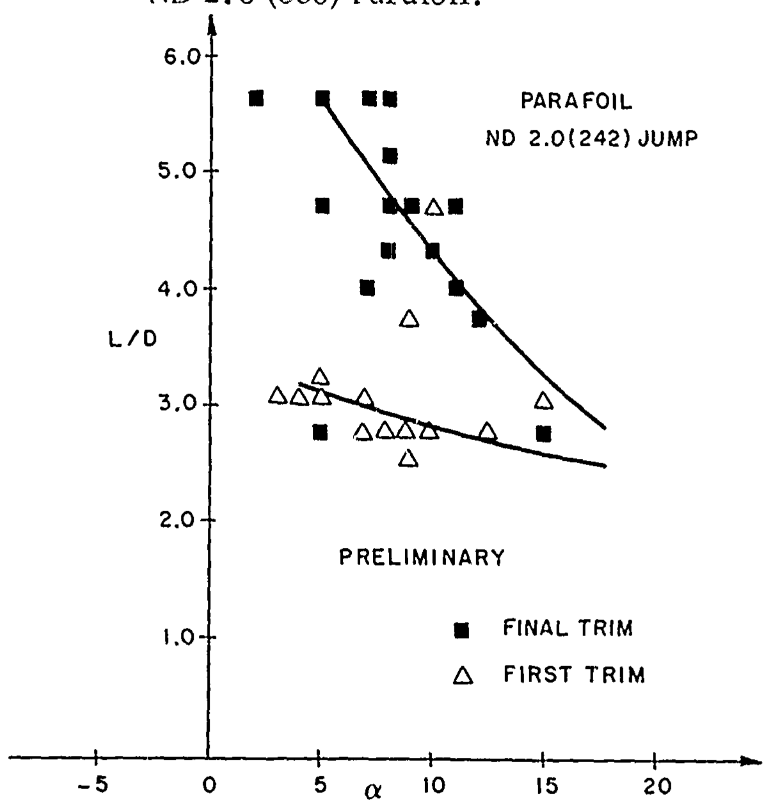



Figure 10. Lift-to-Drag as Function of Angle of Attack for ND 2.0 (242) Parafoil.

from unmanned ascending flights, manned ascending flights, cart flights, and manned jumps. Free-flight lift-to-drag ratios obtained by using the trailing smoke technique on Parafoil ND 2.0 (360) are given in Figure 9. This data was obtained from manned and unmanned contractor ascending flights and from drops carried out by the U. S. Navy at El Centro. Free-flight lift-to-drag ratio data obtained by contractor using the trailing smoke technique on Parafoil ND 2.0 (242) is given in Figure 10. This data was obtained from contractor ascending flight tests and from live jumps carried out by the U. S. Army Golden Knights at Ft. Bragg.

In general, the lift-to-drag data as obtained from free-flight tests is usually higher than wind tunnel measurements. The higher values are perhaps due to the larger Reynolds number providing an earlier turbulent boundary layer on the upper surface, thereby delaying separation of the flow.

## SMALL PARAFOIL DEVELOPMENT

As presented in previous data, large scale Parafoils have been developed and successfully used in a wide range of applications.[11,12] Until recently, however, small units had been somewhat neglected. Therefore, in order to further develop the capabilities of the Parafoil, units with an area of 4.5 square feet and an aspect ratio of 2.0 were designed and tested. At the request of the Air Force Armament Laboratory, Eglin Air Force Base, a research p ogram was initiated to test small units for the delivery of bomblet munitions. The main objective of this program was to test a 4.5-square-foot, aspect ratio 2.0 Parafoil unit which would have stable flight, good deployment, and good glide characteristics.

The first small Parafoil tested in this program is shown in Figure 11. Initially, extensive tethered flight tests were conducted. This line of testing was used because units that have flown well as kites in the past have exhibited excellent flight characteristics. After considerable tethered and additional gliding and deployment tests, this unit was found to have a lateral instability. During gliding tests, this instability caused the simulated bomb load to develop a pendulum-type motion. In addition, during tethered tests in high winds, the unit tended to oscillate about the longitudinal axis.

This first unit was designed with a single flare because of a desire for simplicity. However, wind tunnel and full scale experimentation with flare designs have indicated that this single flare had a predominate effect on the overall stability and performance of the unit. The first flare point carries a majority of the aerodynamic load and, if not positioned correctly, stability and flight characteristics will suffer. In order to overcome this problem, a second unit which incorporated a two-flare configuration (Figure 12) was tested. The second flare eliminated the longitudinal

oscillation and improved the tethered flight characteristics. However, this unit still suffered from a slight lateral instability in gliding flight.

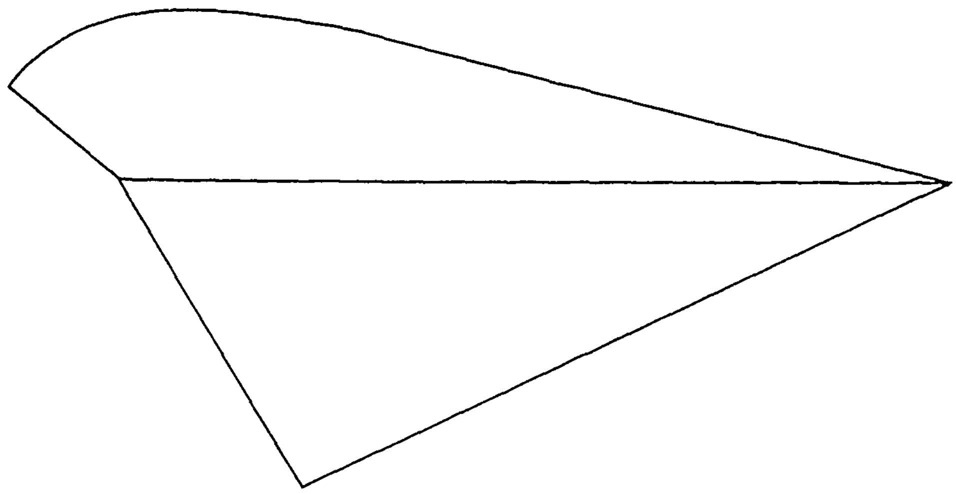


Figure 11. Single Flare Parafoil.

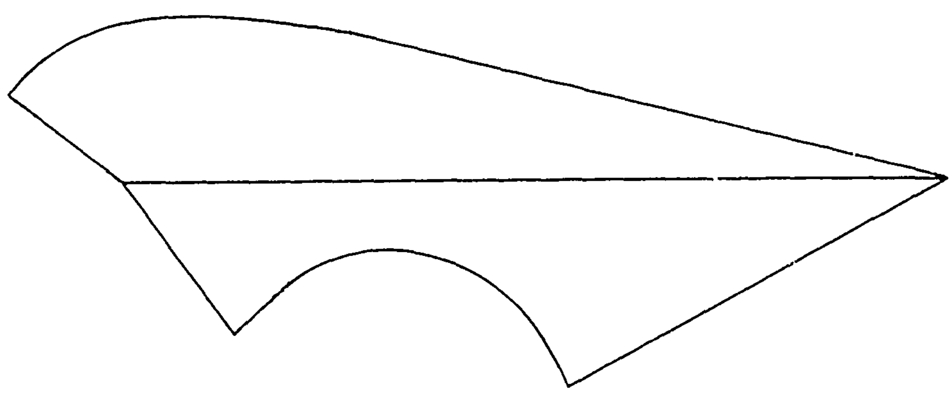


Figure 12. Double Flare Parafoil.

Because of the improved performance of the two-flare unit, a third unit which used three flares (Figure 13) was tested. In this case, roughly 80 percent of the load was being carried by the two front flares. Tethered and gliding flight tests indicated that this unit had excellent flight performance. The bomb load exhibited no pendulum type motion. A new packing sleeve was constructed, and extensive flight tests have demonstrated that this unit had excellent flight performance. The bomb load exhibited no pendulum-type motion. A new packing sleeve was constructed and extensive flight tests have demonstrated that this unit has good deployment characteristics. Gliding flight tests have also indicated that this small unit of aspect ratio 2.0 has an L/D as given by the wind tunnel data.

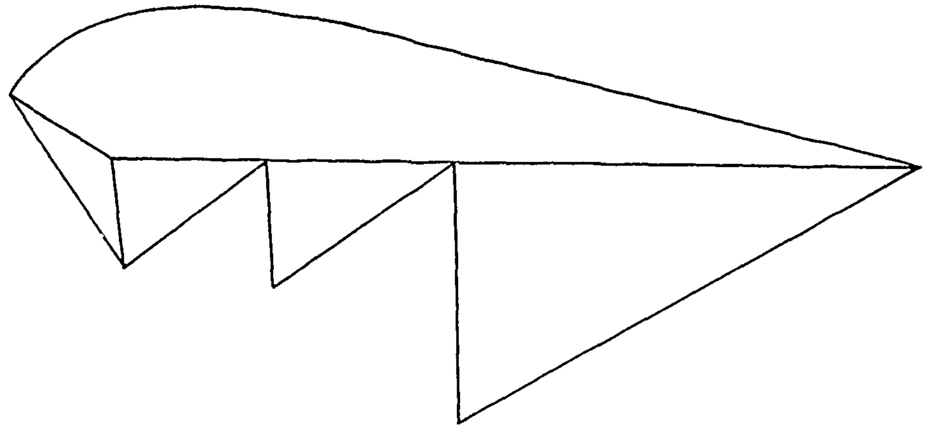


Figure 13. Triple Flare Parafoil.

Numerous gliding tests of this small unit have been conducted at the contractor's facility. These tests have shown that a properly rigged unit will give an excellent flight performance. As a result, the importance of correct rigging cannot be over-emphasized. Small units differ from larger ones in that even small errors and imperfections in the rigging will change flight characteristics. Great care must be taken to insure that all lines are of the correct length and that they will not stretch or deform permanently. Line stretch will cause the same problems as incorrect rigging. Even if line stretch and rigging are corrected, problems might arise as a result of construction asymmetries. Close cooperation was required between the design team and the construction company to insure that close tolerances were held in the construction of the small unit. As with rigging problems, effects of flight performance as a result of slight asymmetries will be greatly magnified in the smaller units.

Once the rigging and construction problems were solved, several of the small three-flare units were tested. These finalized units were tested[d] for the Air Force and were found to have excellent flight performance. In order to get further information, the contractor independently constructed units of aspect ratios 2.4 and 2.8. The performance of these higher aspect ratio units was an improvement over the 2.0 aspect ratio units. However, all tests have demonstrated that the units of 4.5 square feet and aspect ratio 2.0 will serve very satisfactorily for the delivery of bomblet munitions. Units of this design have subsequently been shipped to the Air Force Armament Laboratory for further tests and evaluations.

---

[d] The Parafoil flight testing program included kite tests, ascending and gliding tests, and aircraft drops.

## CONCLUSIONS

It is concluded from the small Parafoil flight test program that the Parafoil ND 2.0 (4.5) may be successfully used for bomblet munitions delivery and will achieve a lift-to-drag ratio greater than 3 and as high as 5.

# SECTION II

# BLU-58/B FLIGHT DATA ANALYSIS

## INTRODUCTION

Ordnance weapon systems have experienced serious flight instabilities which induced large wobbling motions, and the resulting increase in drag has caused significant inaccuracies. These adverse effects were not only detrimental to mission objectives but could have resulted in unwanted casualities. Therefore it became imperative that the aerodynamic characteristics of these weapons be accurately determined.

To accomplish this purpose, both free-flight and wind tunnel tests on these weapons had to be conducted to ascertain their stability parameters from angular data. To this end, the Air Force Armament Laboratory requested the contractor to conduct an analysis of free-data for the BLU-58/B bomb, a blunt-nosed, high-density, retarded device for supersonic carriage and release. Analysis of the ballistic data from 19 flight tests of the bomb are recorded in Reference 13.

For the analysis of free-flight drop tests, the contractor has furnished eight sets of data consisting of computer listings of the angles of pitch and roll as well as the opening angle of the retardation device as a function of angle of attack. The purpose of the analysis was to determine the restoring moment stability coefficient, $C_{m\alpha}$, from the flight data.

## BLU-58/B CONFIGURATIONS

The BLU-58/B is a 500-pound general-purpose, retarded bomb designed for high-density pod carriage and delivery at supersonic speeds (Figures 14 and 15).

The retarder is a self-contained, hinged vane mechanism activated by a solid-propellant gas generator. At release, the gas generator is initiated by lanyard withdrawal and the activated gas generator vents into the retarded piston cylinder, forcing the piston and connecting rod aft. Through a mechanical linkage mechanism, six metal retarding vanes are forced outward into the free-stream against the impinging air loads to retard the bomb's forward velocity. To provide added drag and continuity to the deployed drogue, interconnecting fabric panels are installed between the metal vane plates (Figure 15). The mass parameters for this configuration are:

$$I = 14.75 \text{ slug-ft}^2$$
$$d = 1.25 \text{ ft}$$
$$s = 1.23 \text{ ft}^2$$

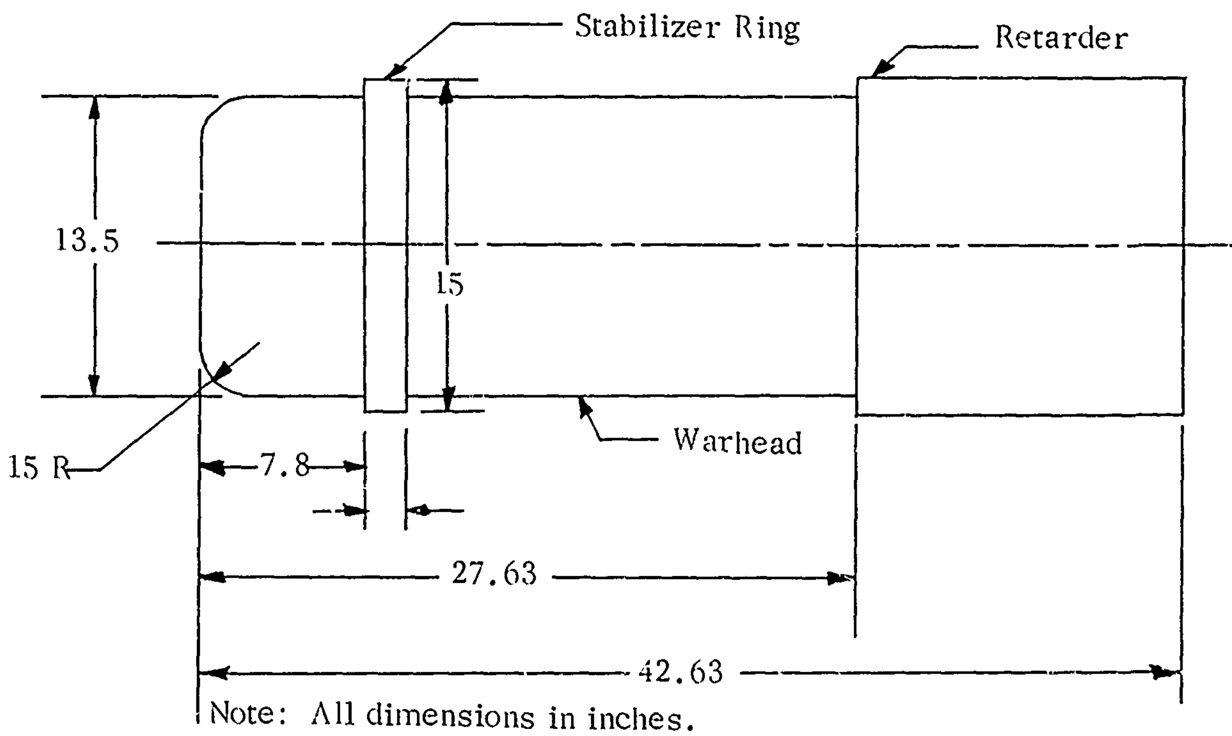



Figure 14. BLU-58/B Low-Drag Configuration.

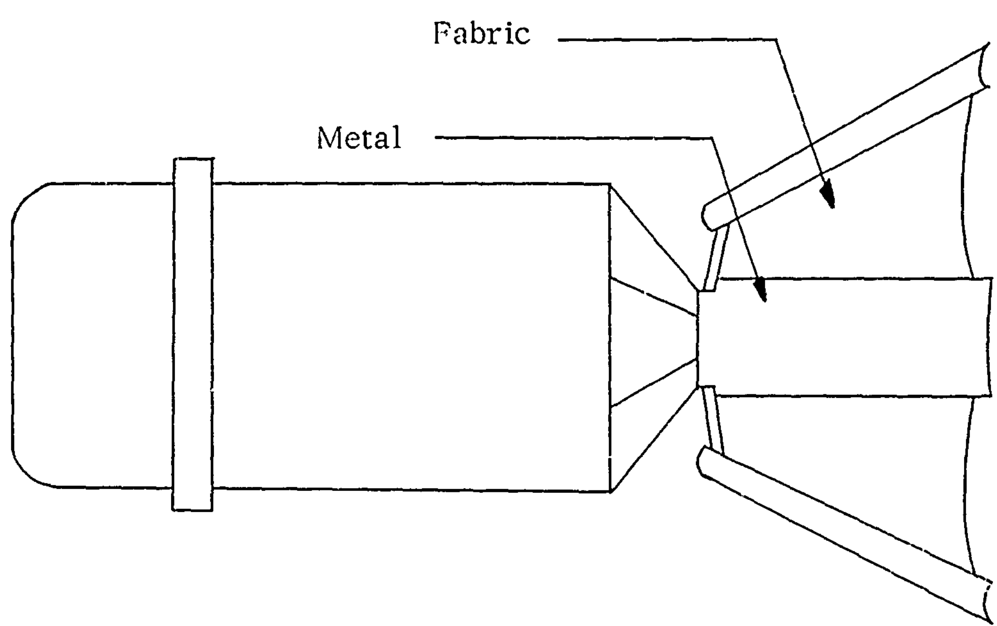



Figure 15. BLU-58/B High-Drag Configuration.

## RESULTS OF ANALYSIS

Eight sets of free-flight data (flights 2,6,7,8,10,11,13 and 14) were plotted for analysis of the BLU-58/B. Pitch angle, roll angle, and vane angle of the retardation device data are shown in Figure 16 through 39. Due to the low quality of this data, only Runs 2 and 6 for the retarded case and Run 10 for the unretarded case were analyzed.

Figures 16 and 19 show that the bomb's angular motion was oscillatory for the retarded case, indicating that it was statically stable. Figures 18 and 21 indicate that a retardation vane opening of 36 degrees was reached in both cases. The flight conditions and their angular frequency used for these two runs were as follows:

| Run | V (Ft/Sec) | Q ($Lb/Ft^2$) | $\omega^2$ $(Rad/Sec)^2$ |
|---|---|---|---|
| 2 | 958 | 1095 | 158 |
| 6 | 993 | 1088 | 247 |

Using the following equation for the restoring moment[14]

$$C_{m\alpha} = - \frac{\omega^2 I}{QSd} \quad (1)$$

computations were made for both Runs 2 and 6. The resulting coefficients were as follows:

| Run | $C_{m\alpha}$ |
|---|---|
| 2 | -1.4 |
| 6 | -2.2 |

The bomb's angular motion was oscillatory in Run 10 also (Figure 28). Essentially, however, its motion was unretarded, as indicated by the fact that the vane angle reached throughout the duration of the flight was zero degrees, i.e., the vanes remained closed (Figure 30). Flight conditions for Run 10 are given below:

| Run | V (Ft/Sec) | Q ($Lb/Ft^2$) | $\omega^2$ ($Rad^2/Sec$) |
|---|---|---|---|
| 10 | 976 | 1090 | 288 |

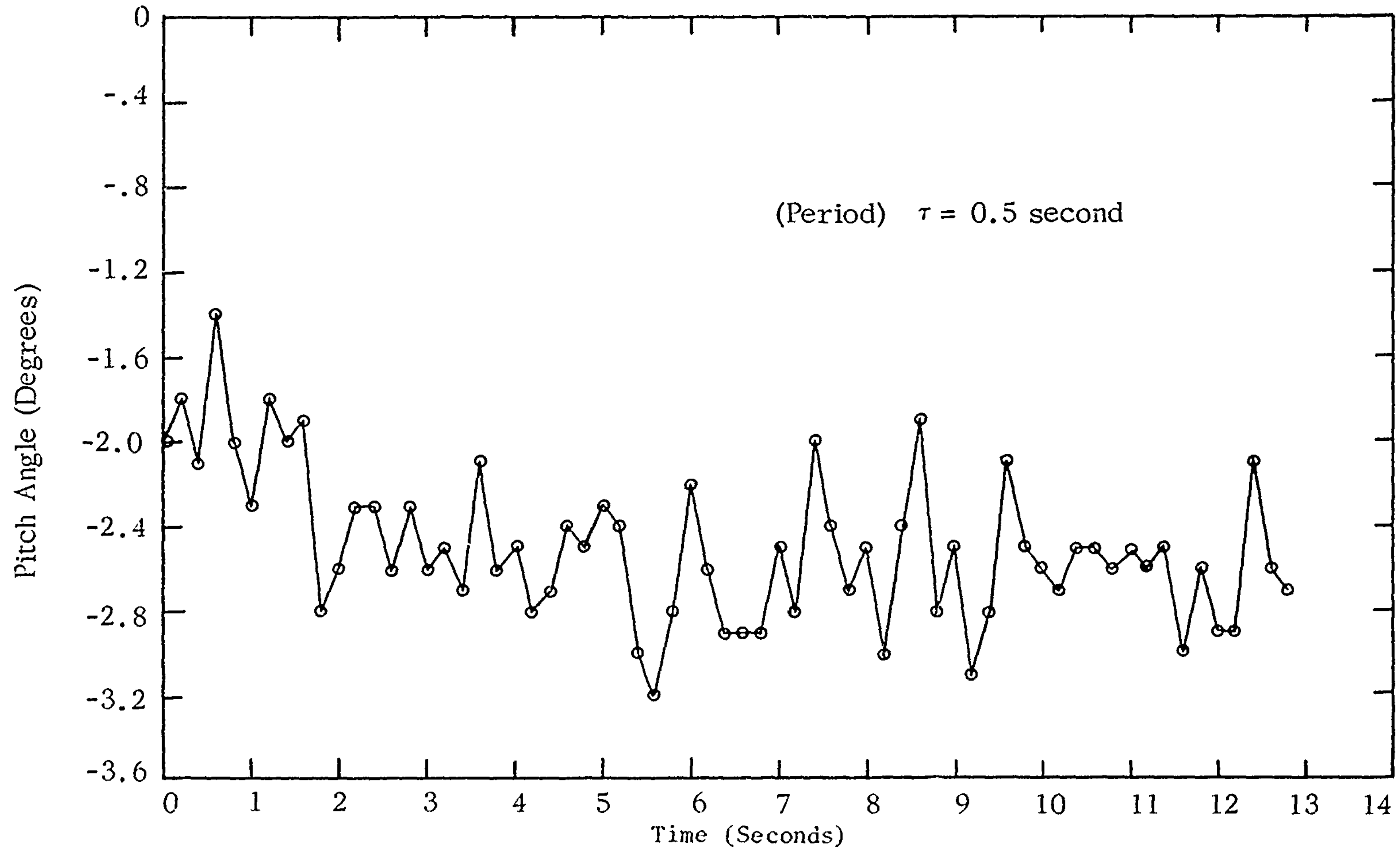



Figure 16. Pitch Angle versus Time - Run #2.

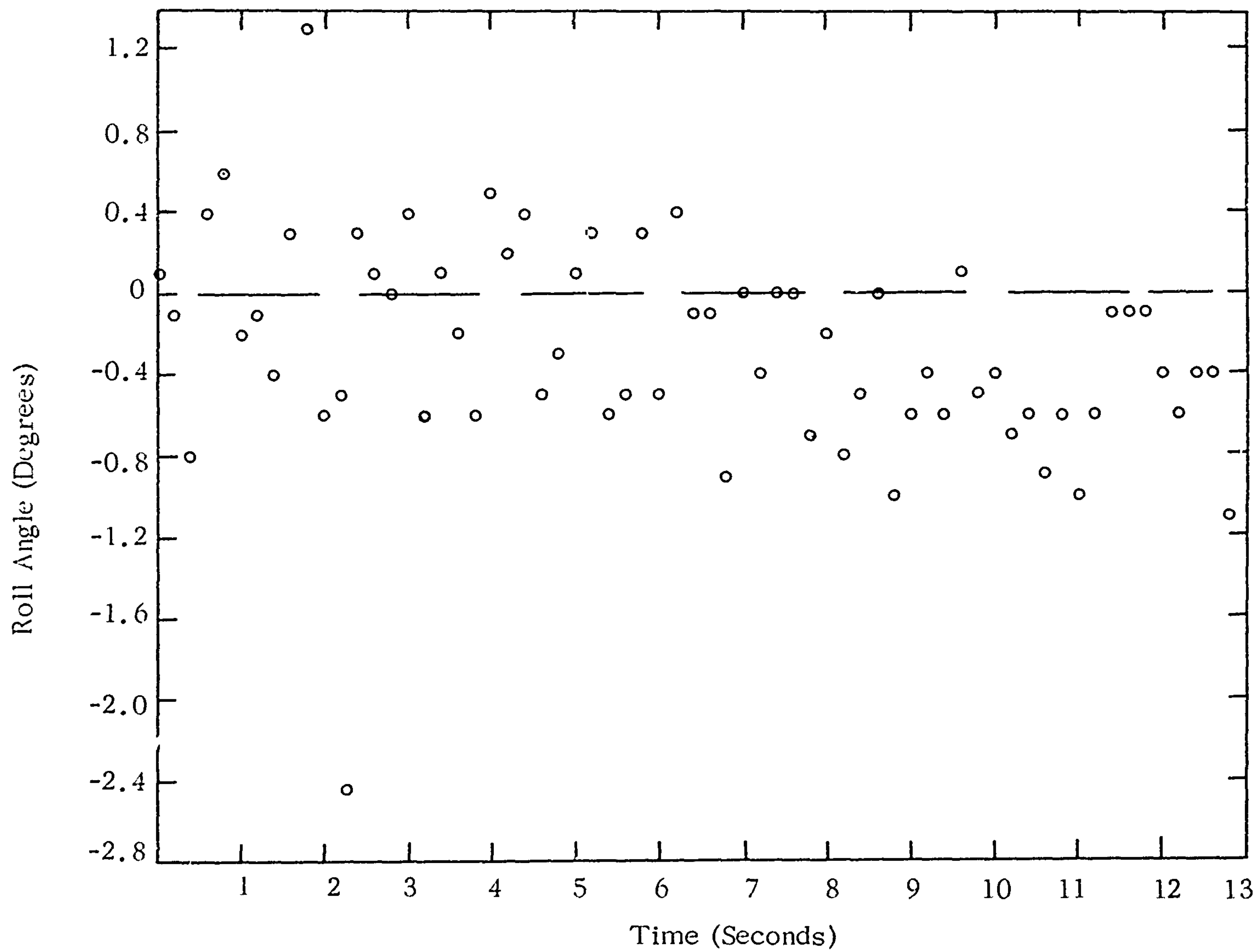



Figure 17. Roll Angle versus Time - Run #2.

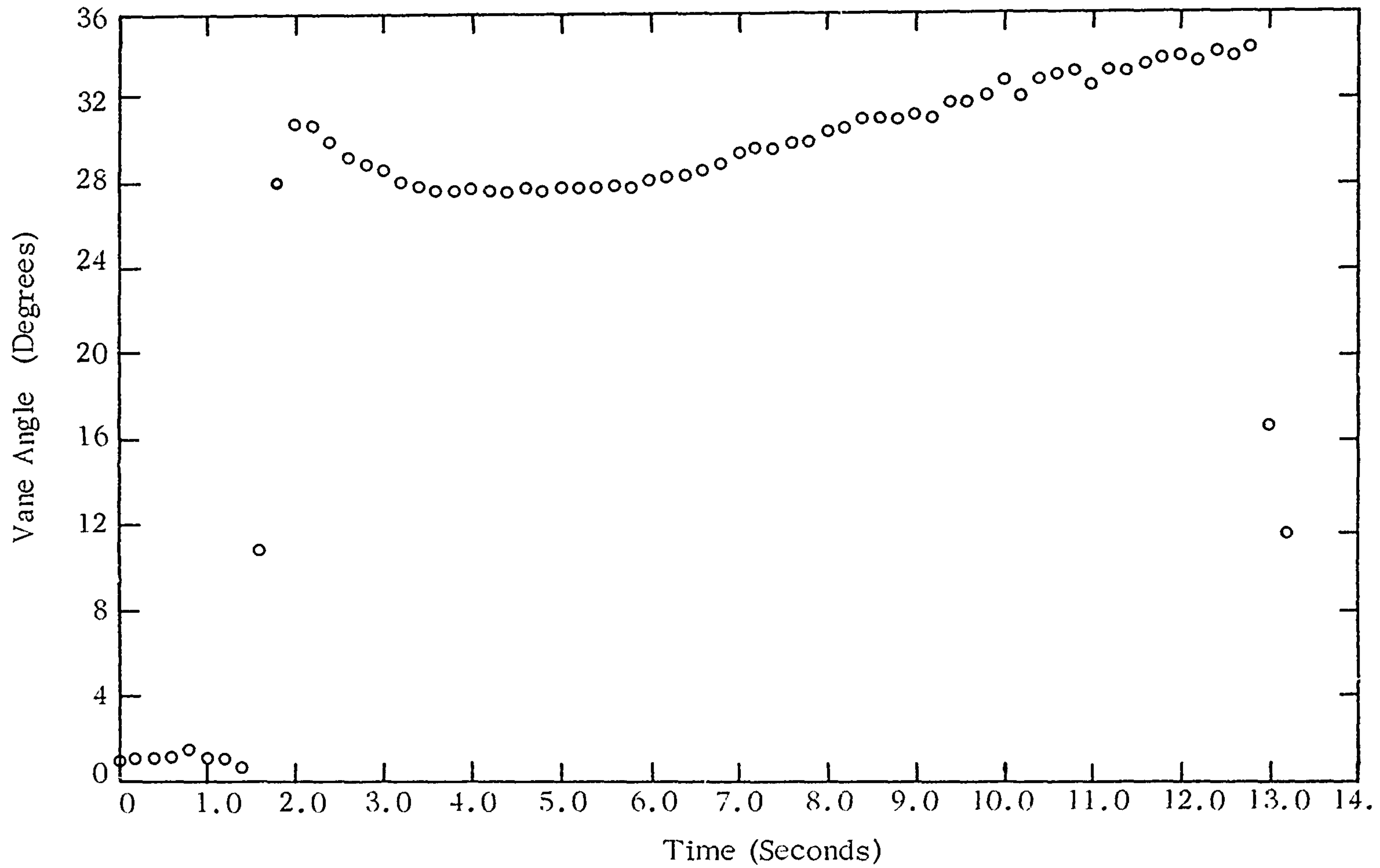



Figure 18. Vane Angle versus Time - Run #2.

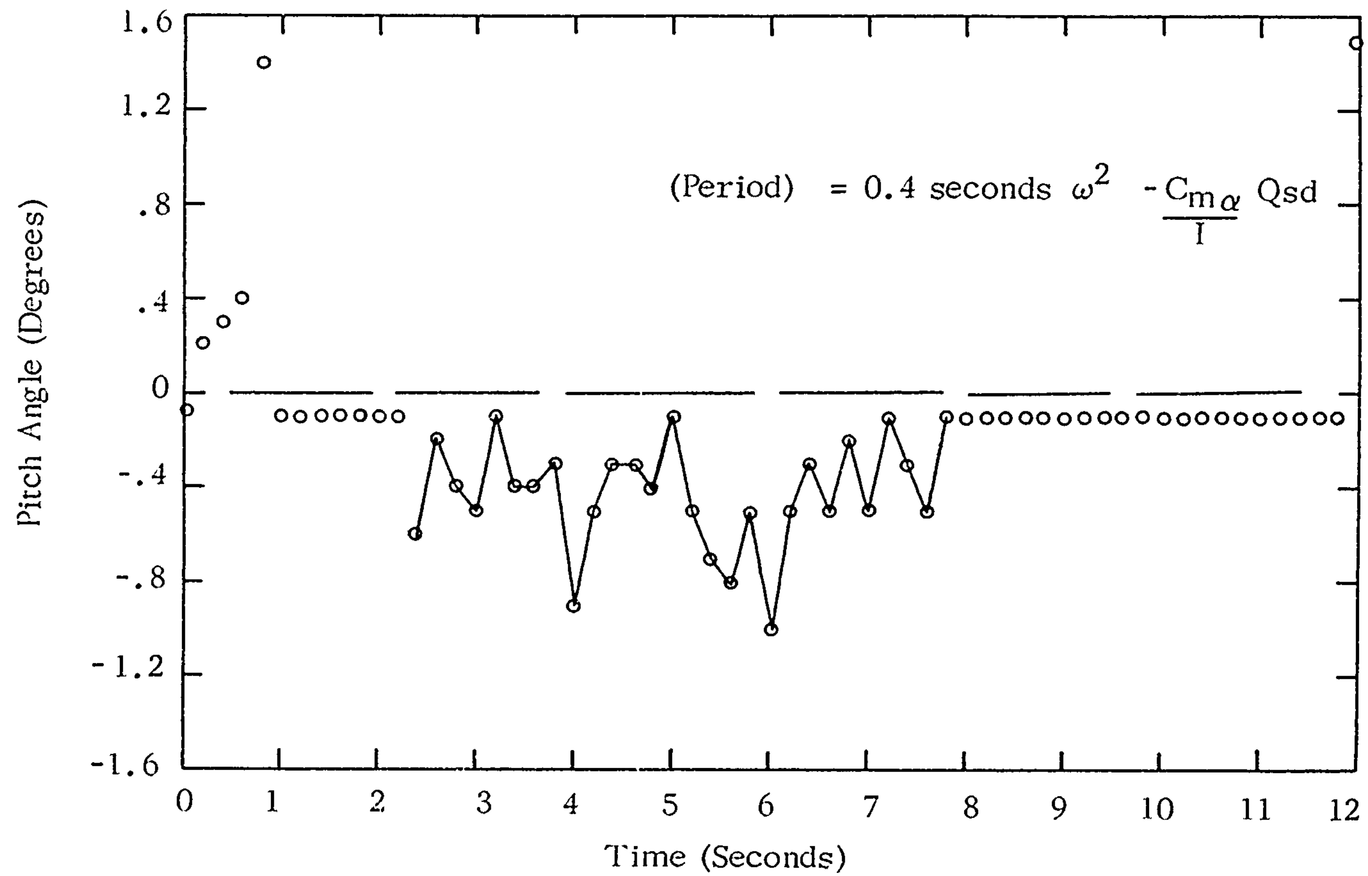



Figure 19. Pitch Angle versus Time - Run #6.

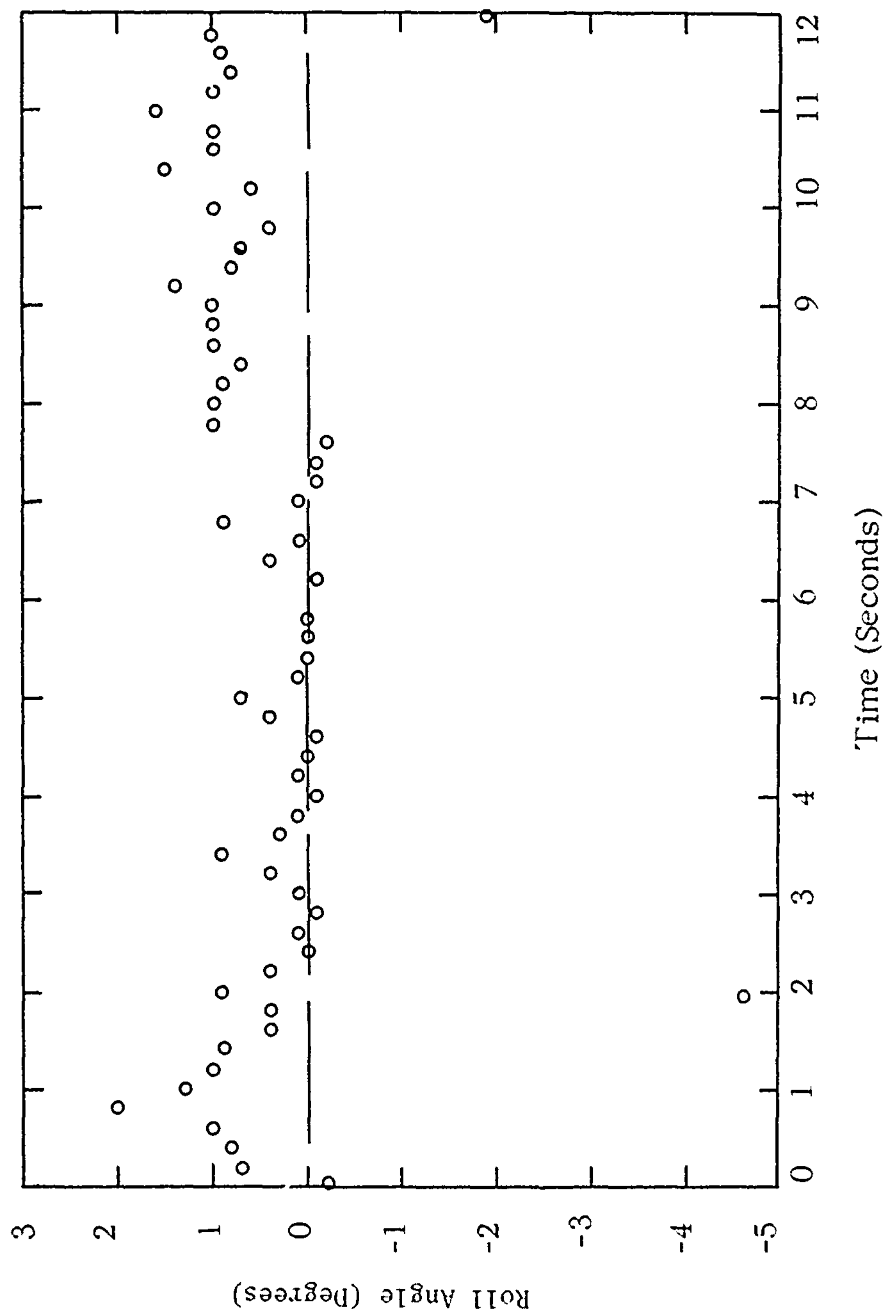



Figure 20. Roll Angle versus Time - Run #6.

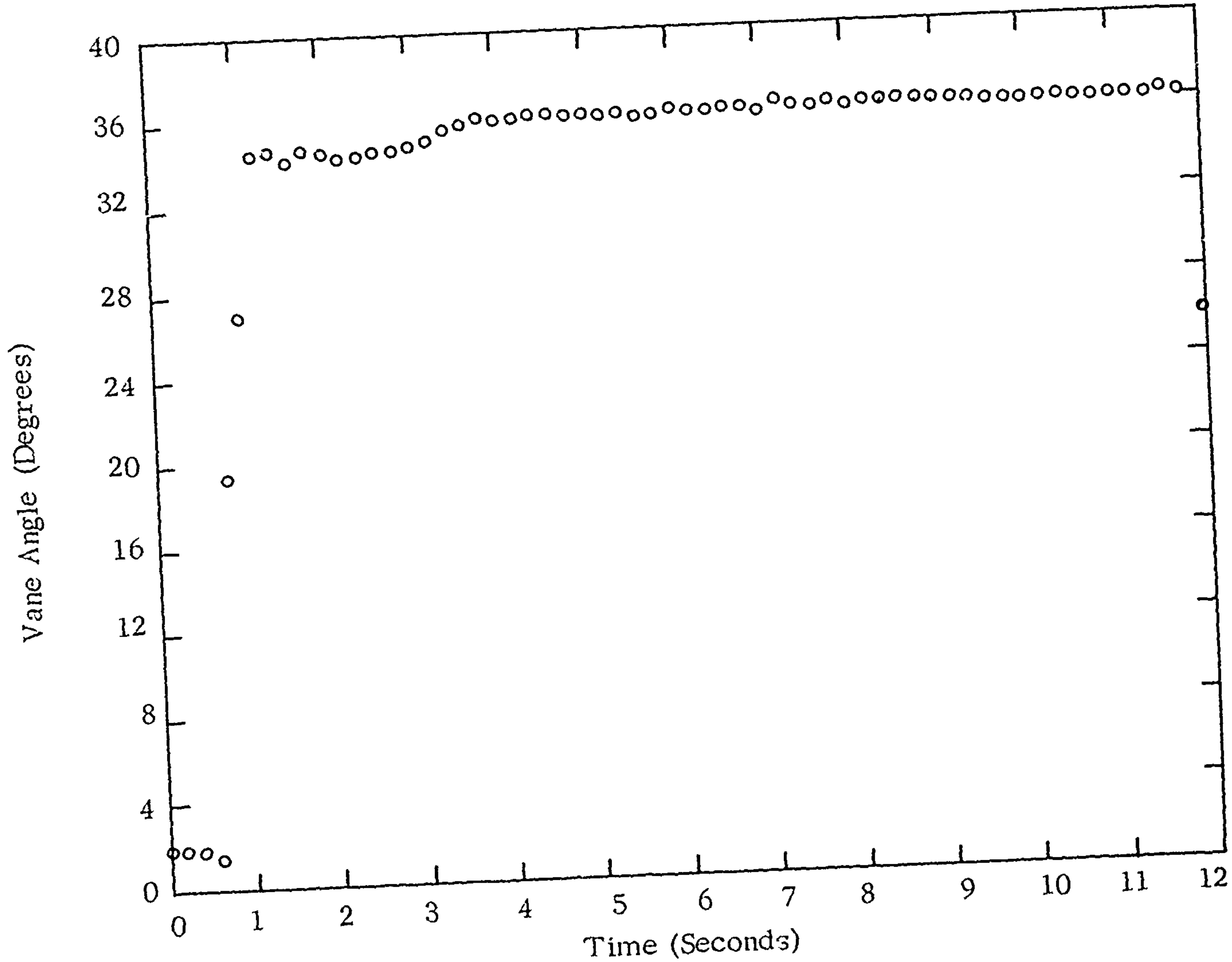



Figure 21. Vane Angle versus Time - Run #6.

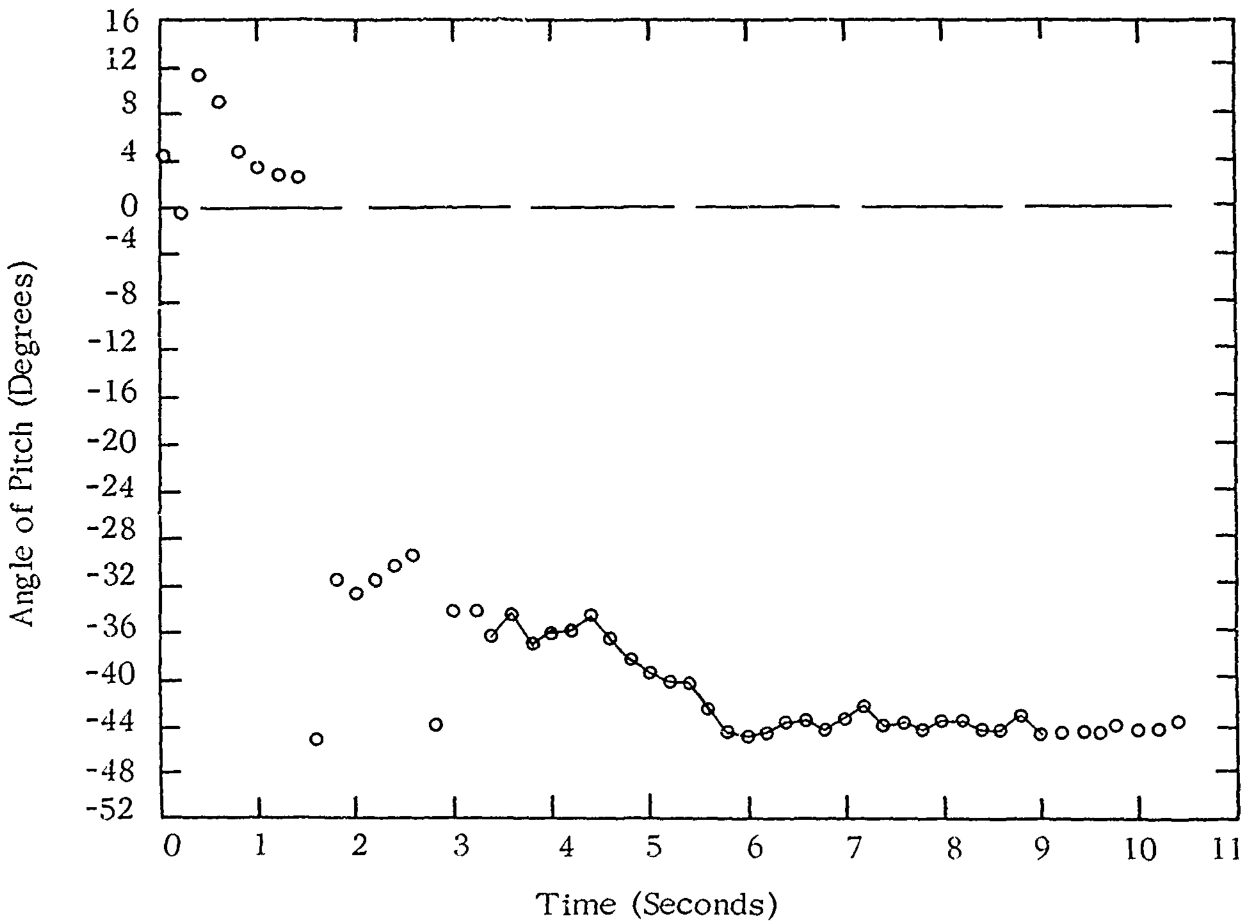



Figure 22. Angle of Pitch versus Time - Run #7.

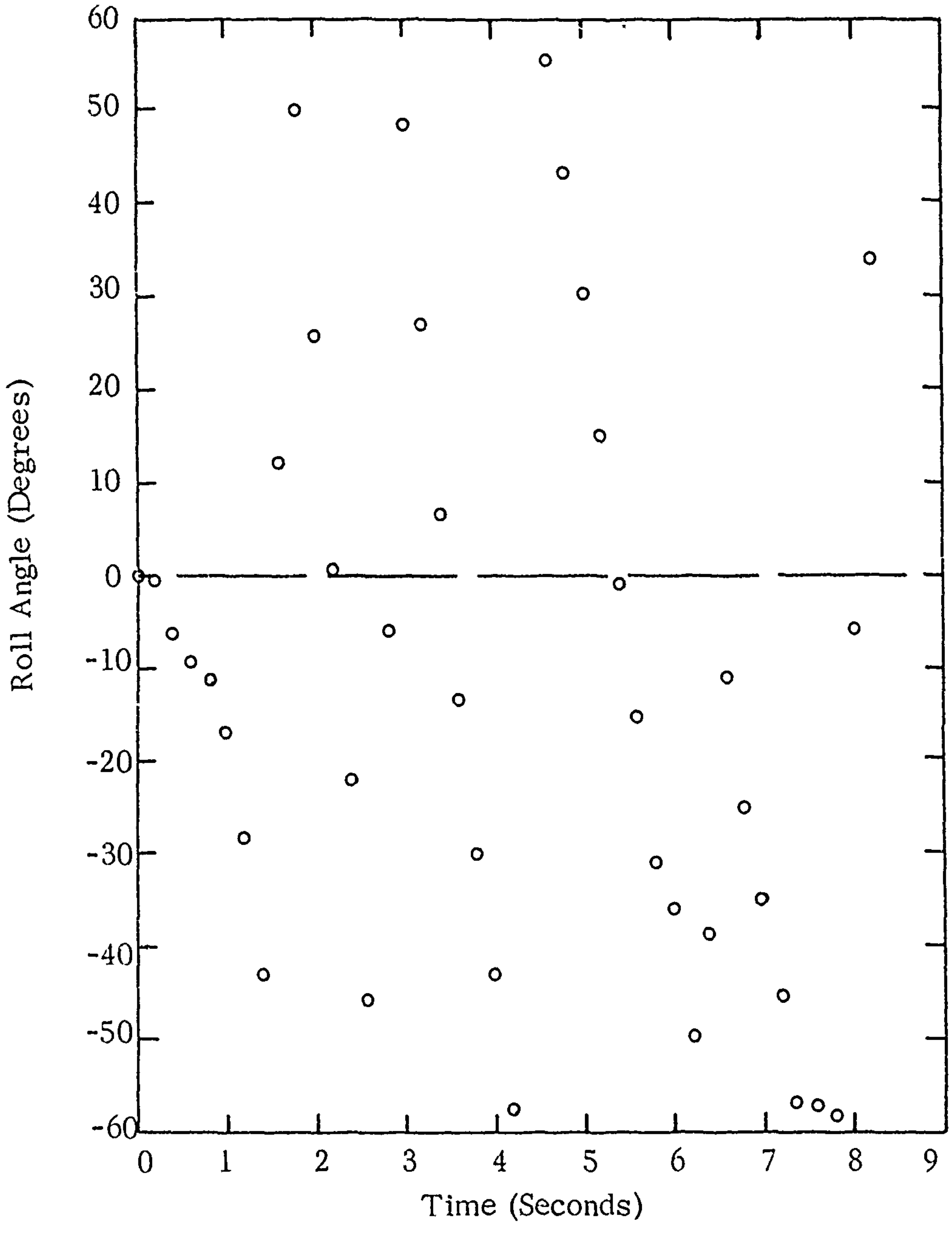



Figure 23. Roll Angle versus Time - Run #7.

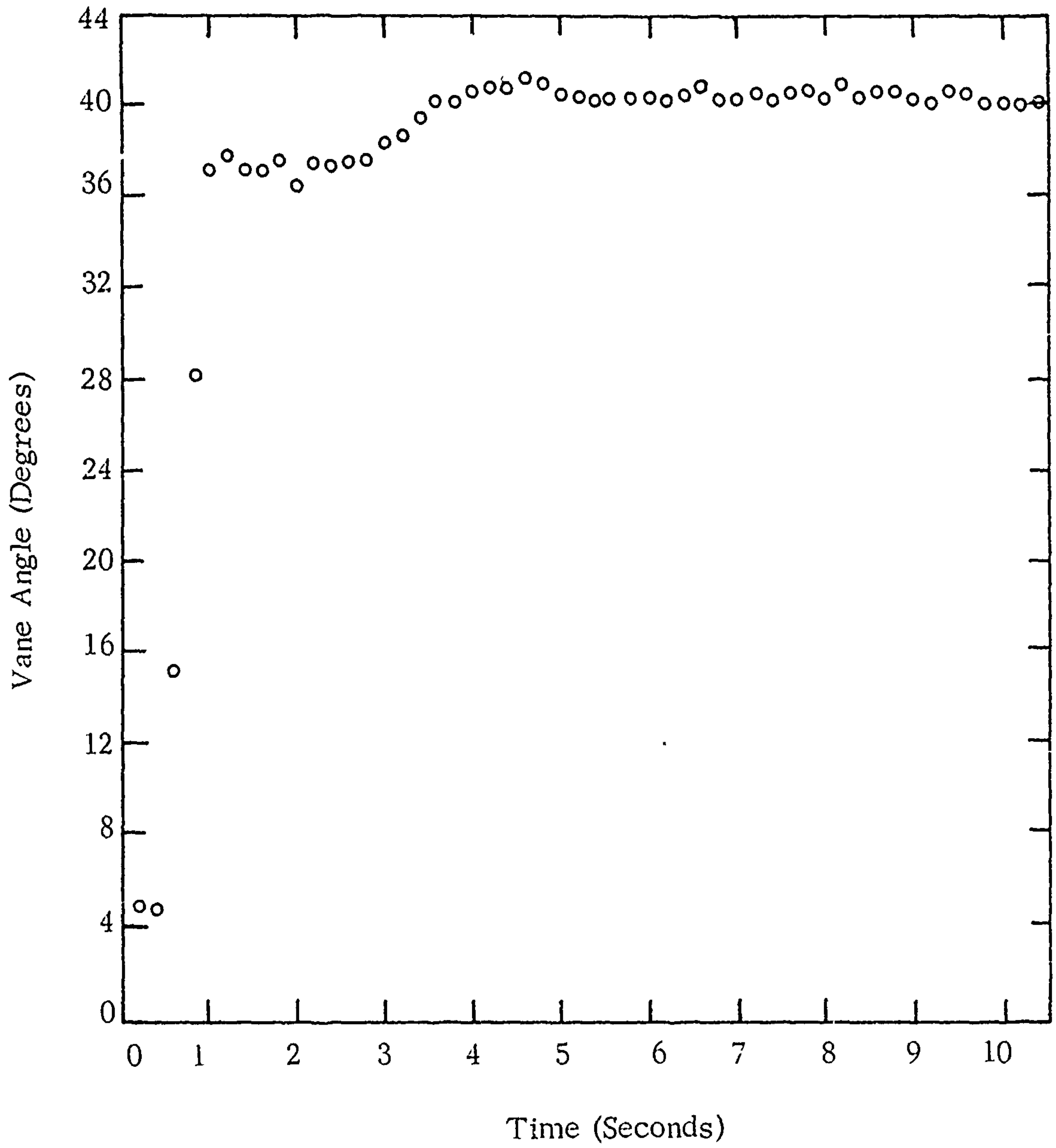



Figure 24. Vane Angle versus Time - Run #7.

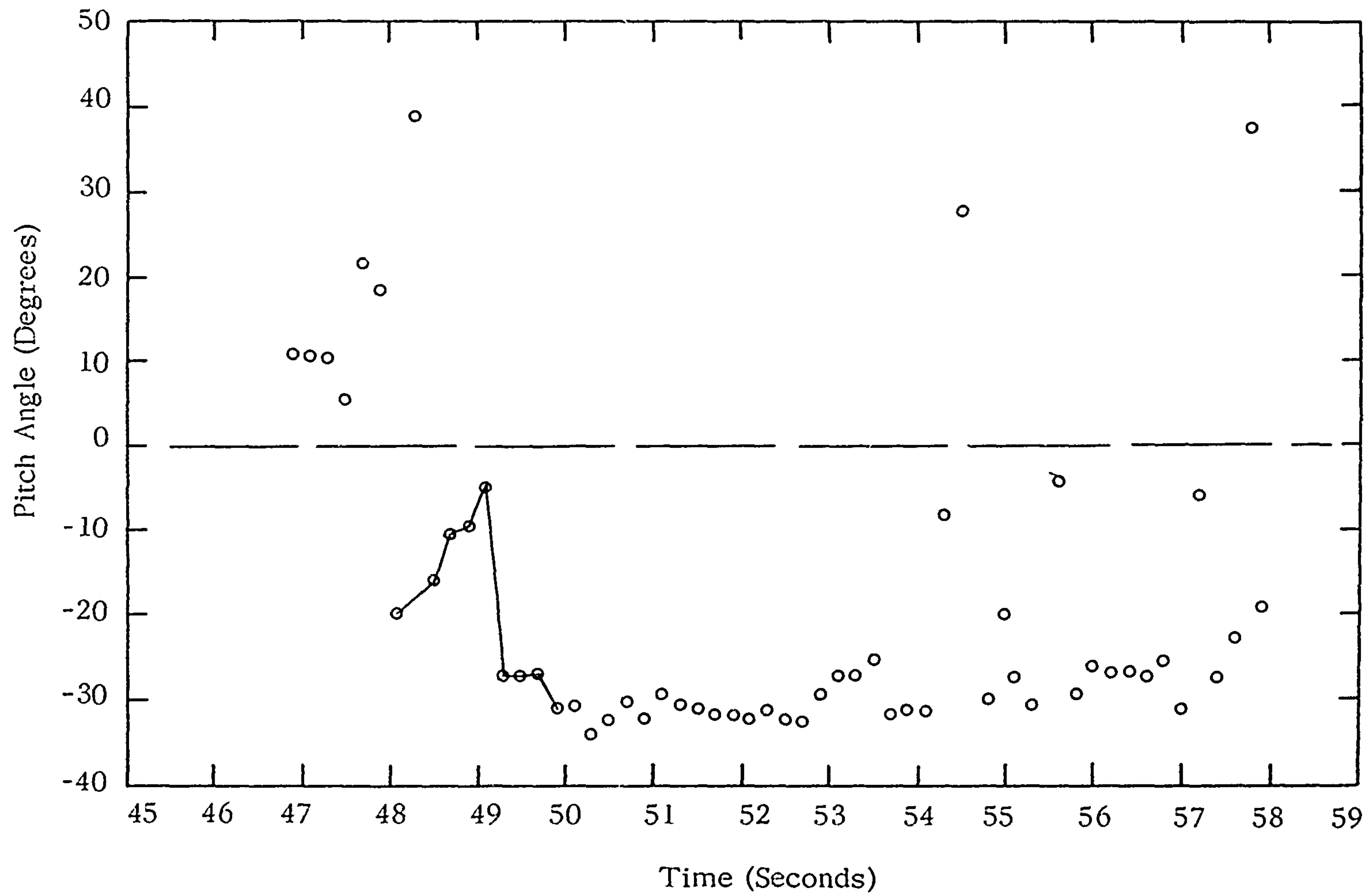



Figure 25. Pitch Angle versus Time - Run #8.

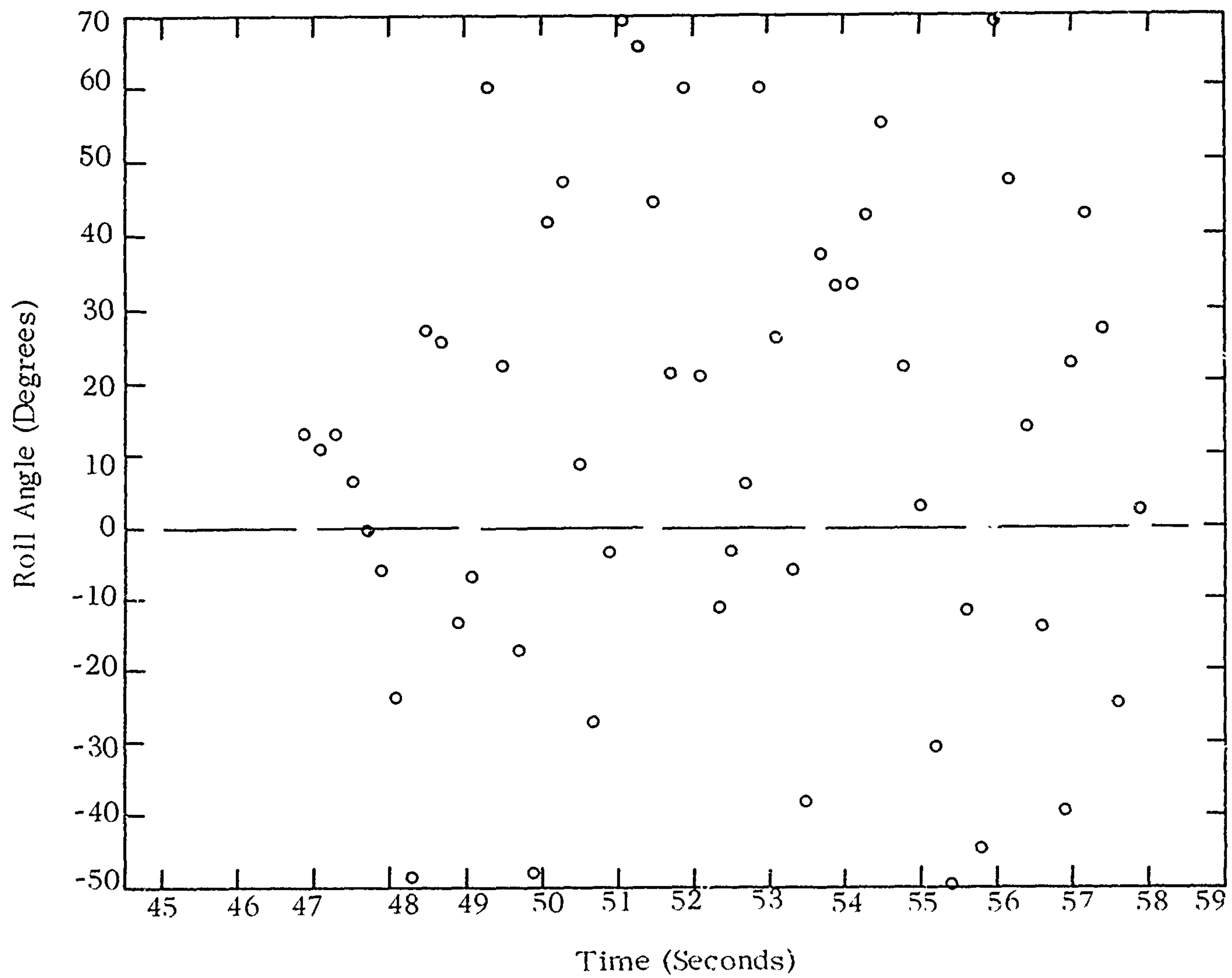



Figure 26. Roll Angle versus Time - Run #8.

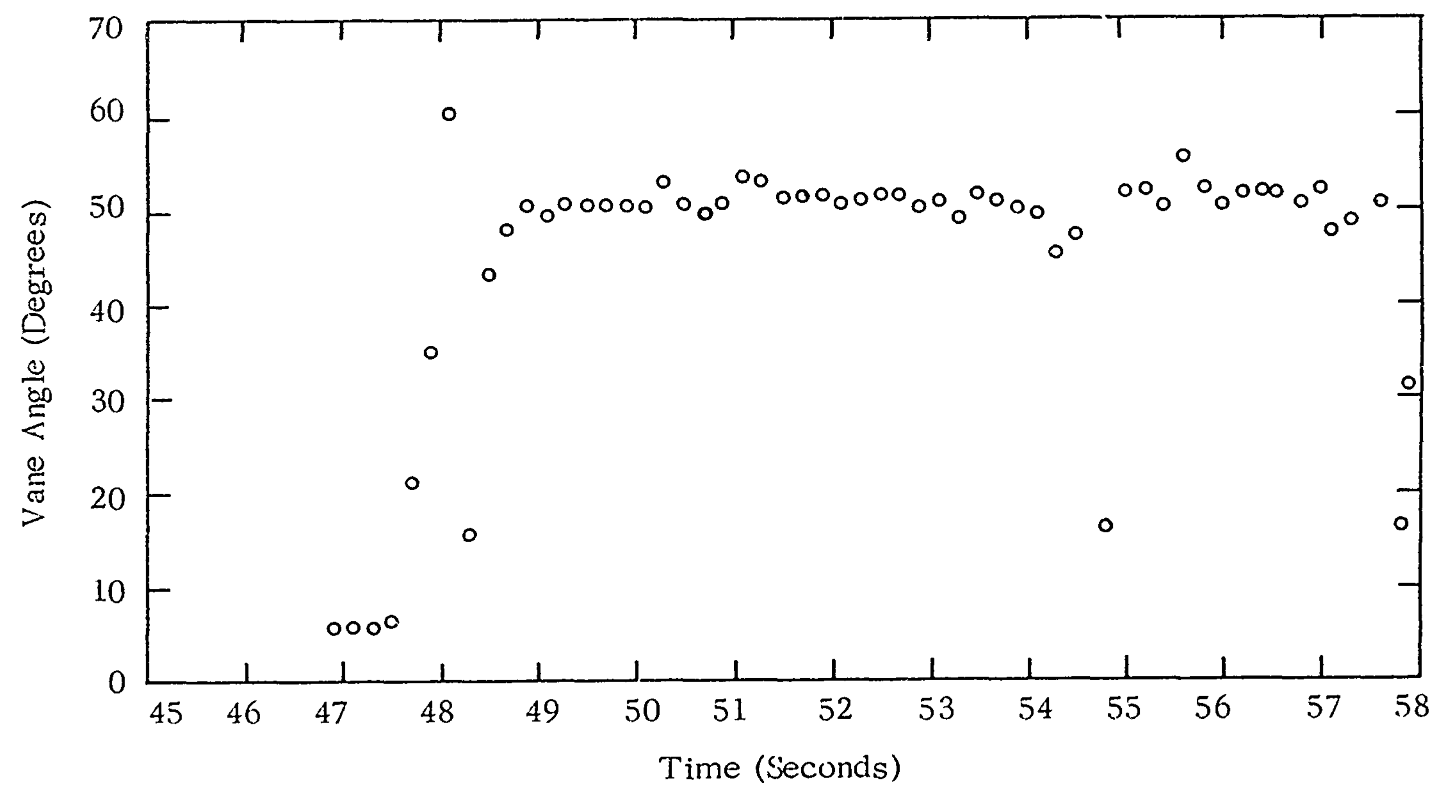



Figure 27. Vane Angle versus Time - Run #8.

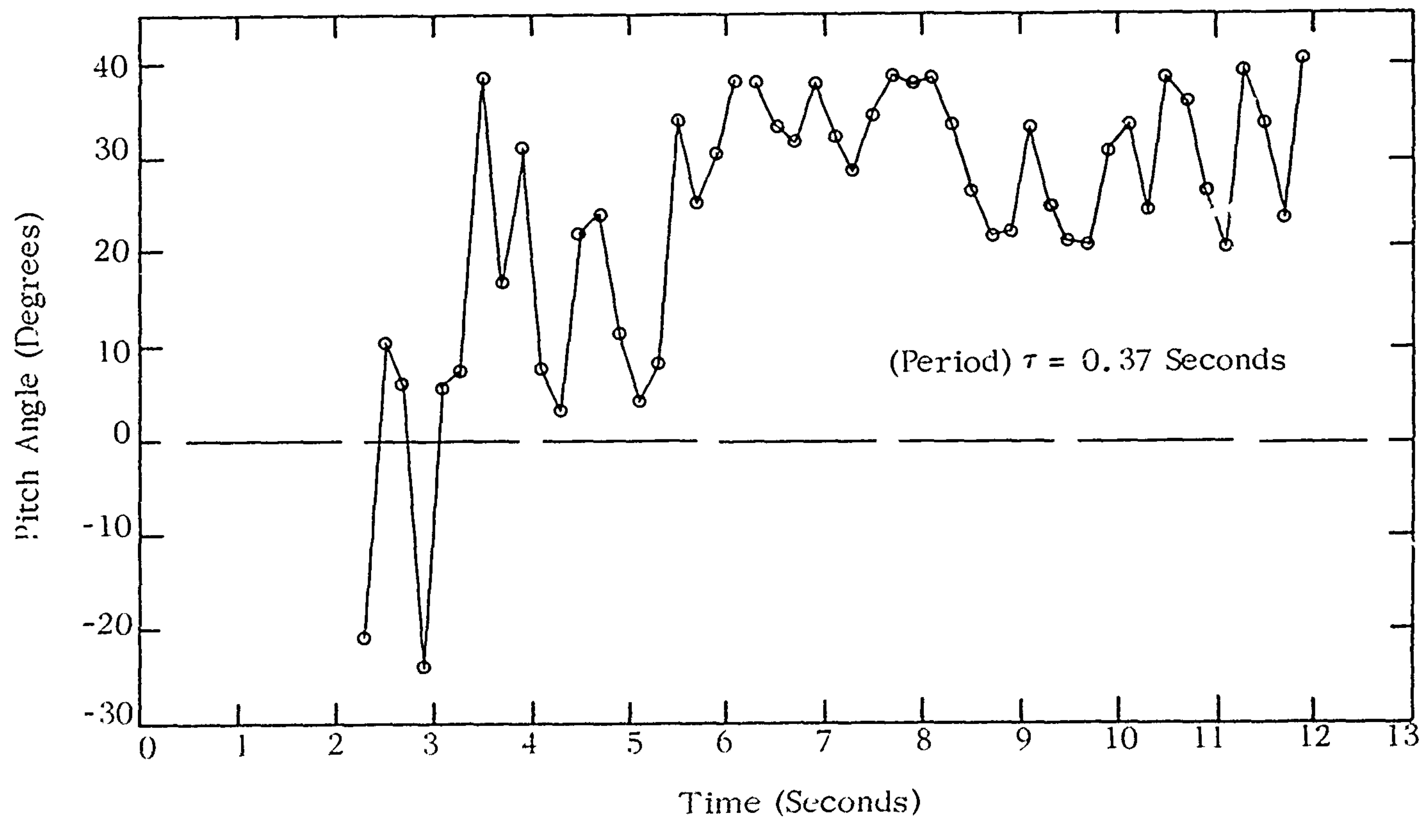



Figure 28. Pitch Angle versus Time - Run #10.

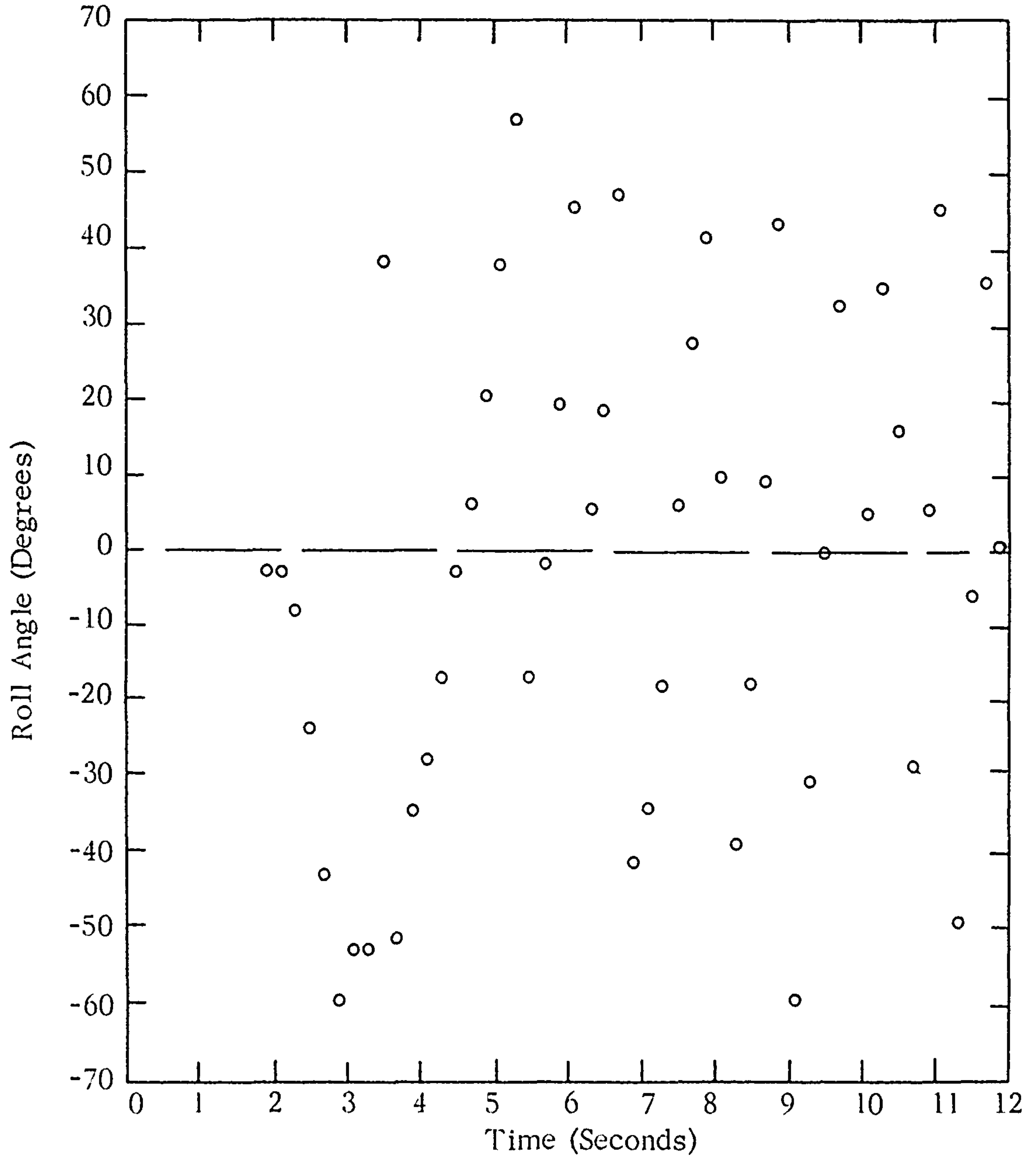



Figure 29. Roll Angle versus Time - Run #10.

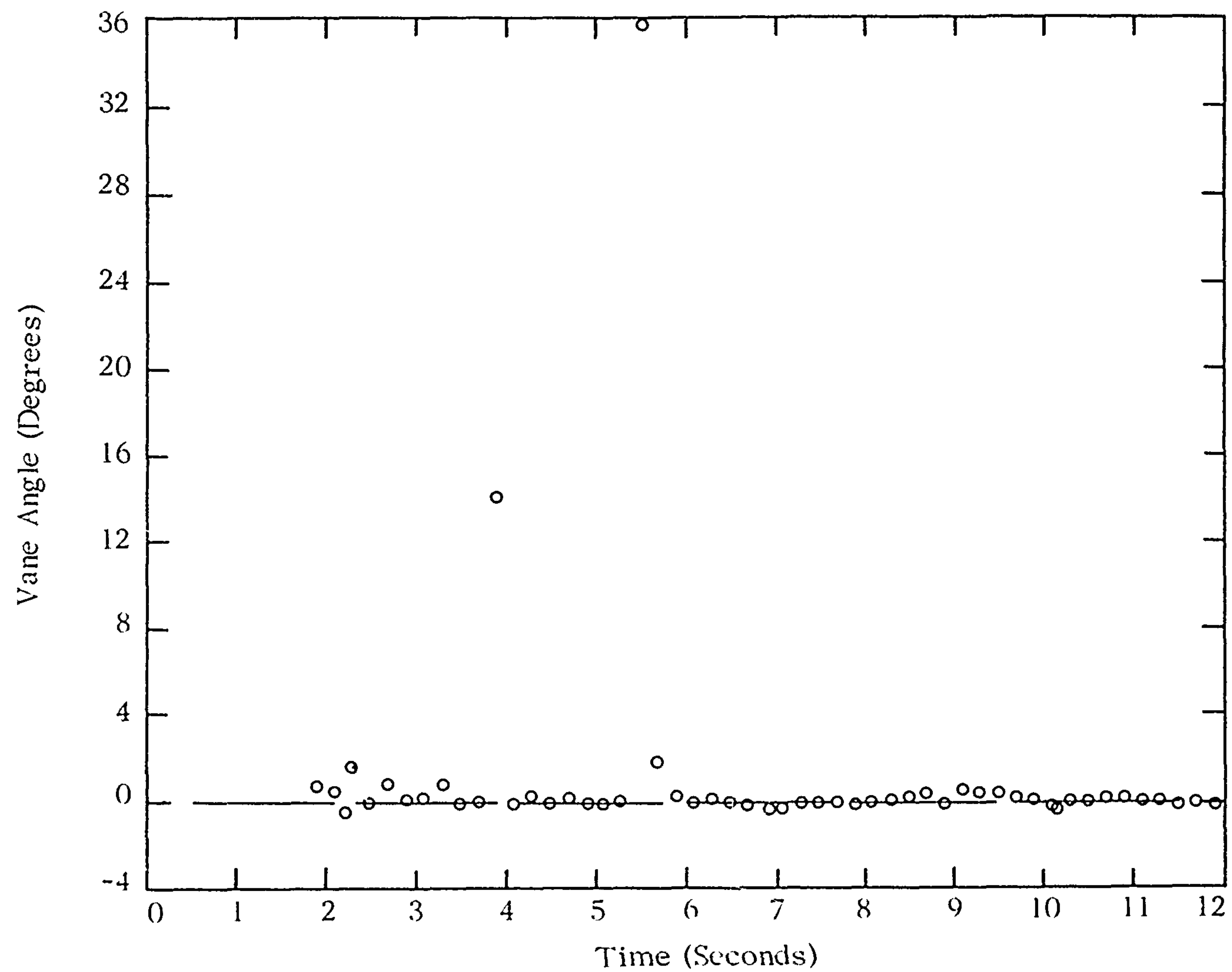



Figure 30. Vane Angle versus Time - Run =10.

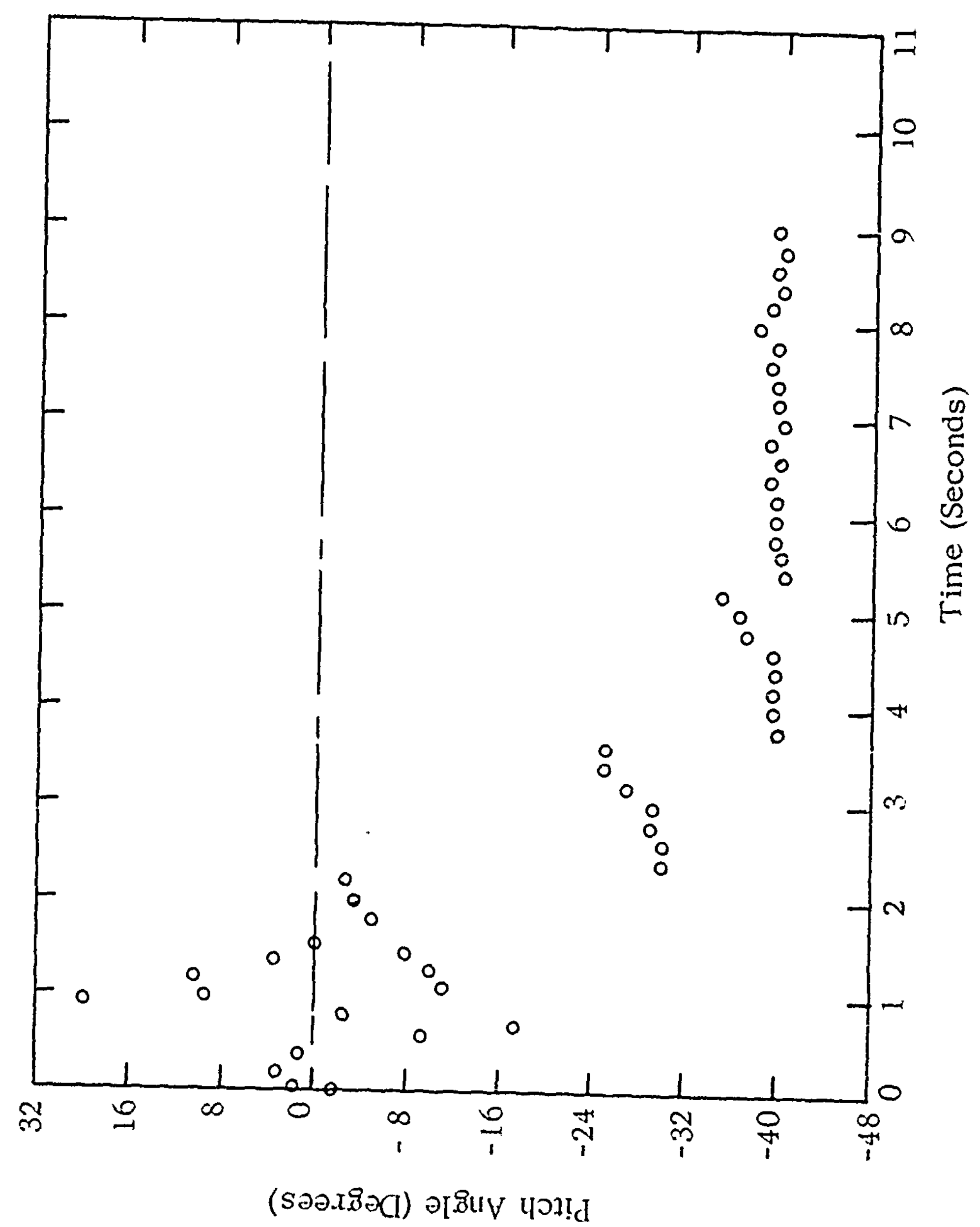



Figure 31. Pitch Angle versus Time - Run #11.

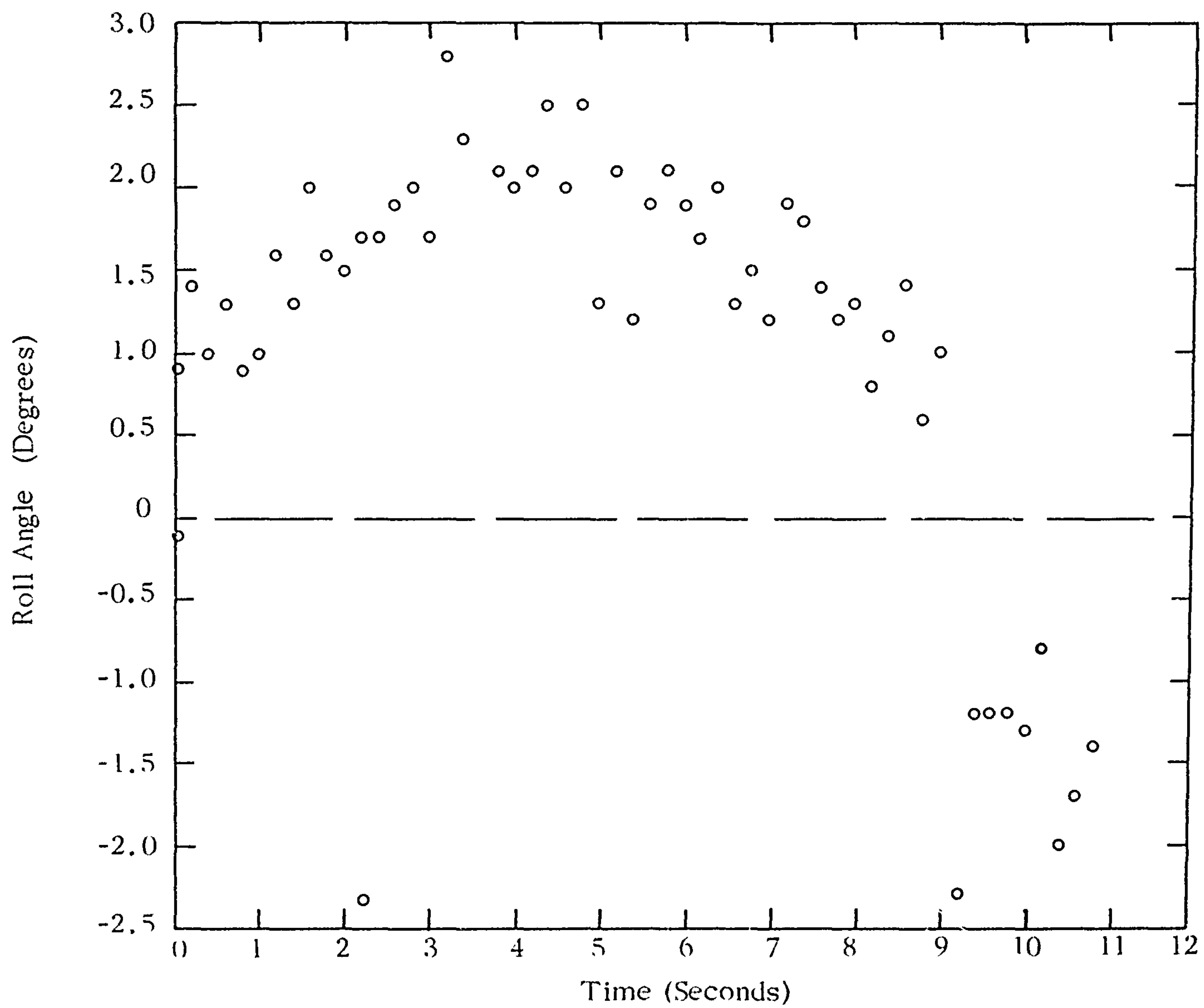



Figure 32. Roll Angle versus Time - Run #11.

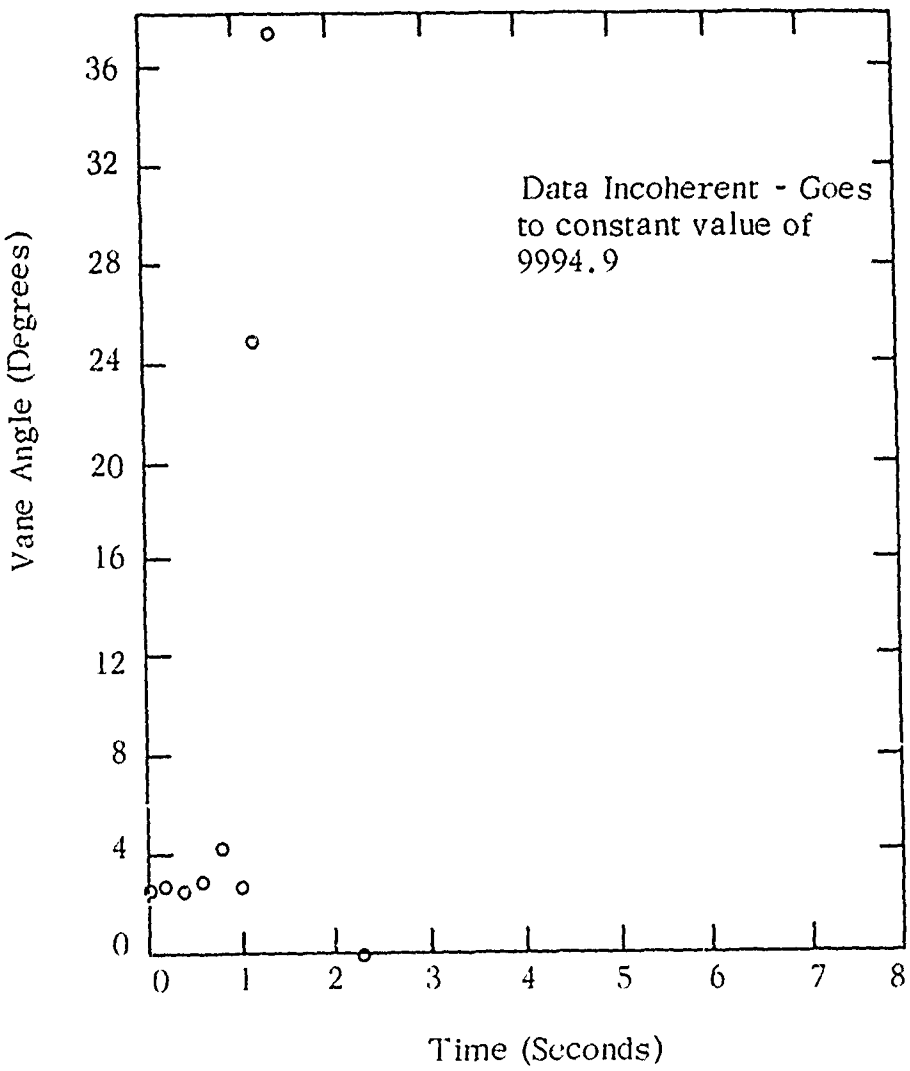



Figure 33. Vane Angle versus Time - Run #11.

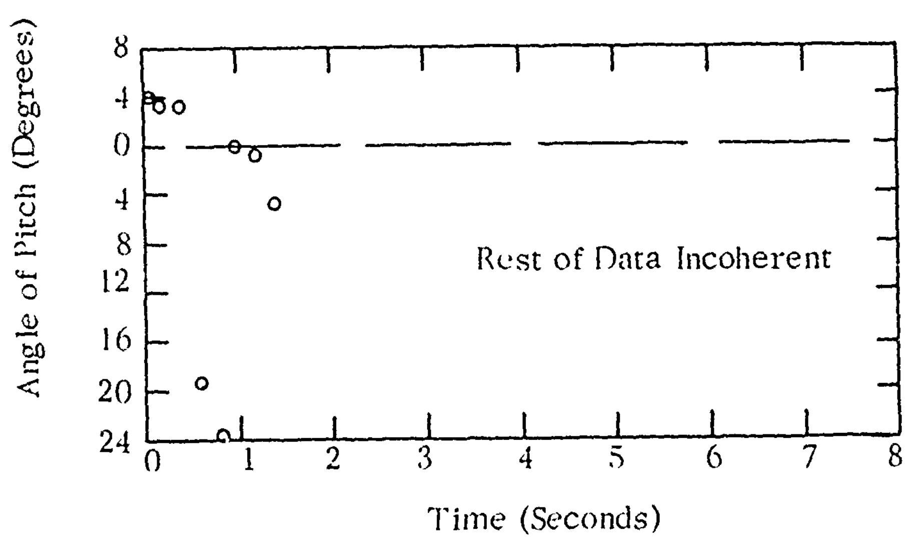



Figure 34. Angle of Pitch versus Time - Run #13.

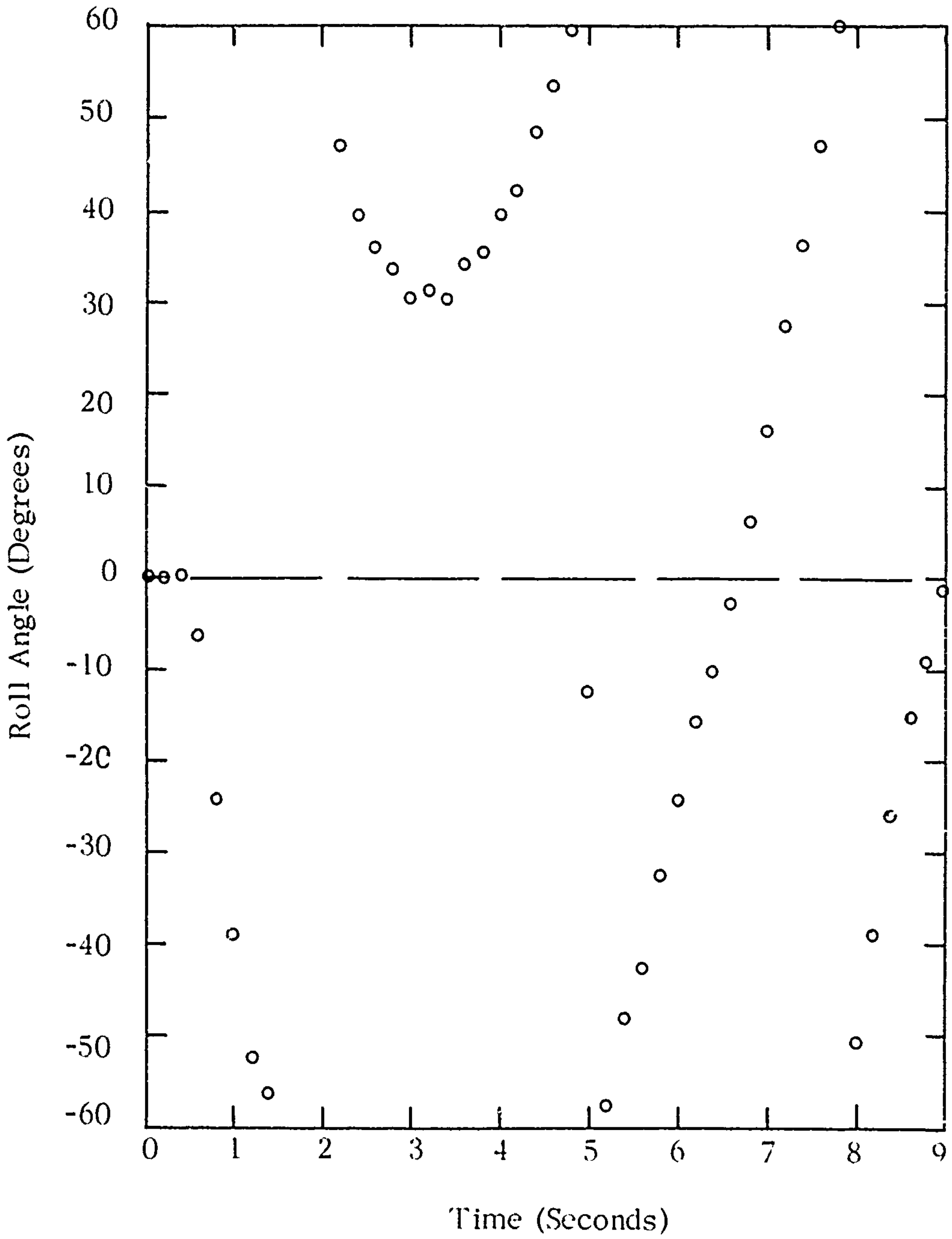



Figure 35. Roll Angle versus Time - Run #13.

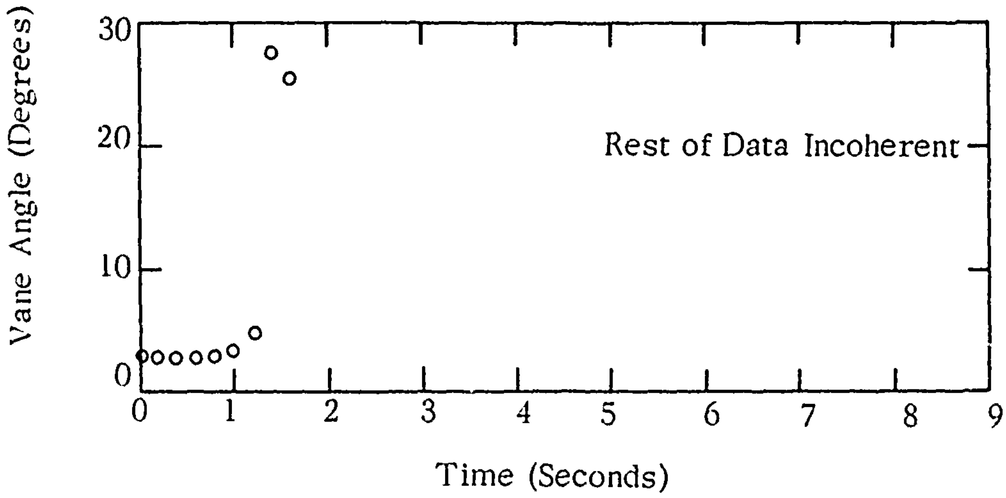



Figure 36. Vane Angle versus Time - Run #13.

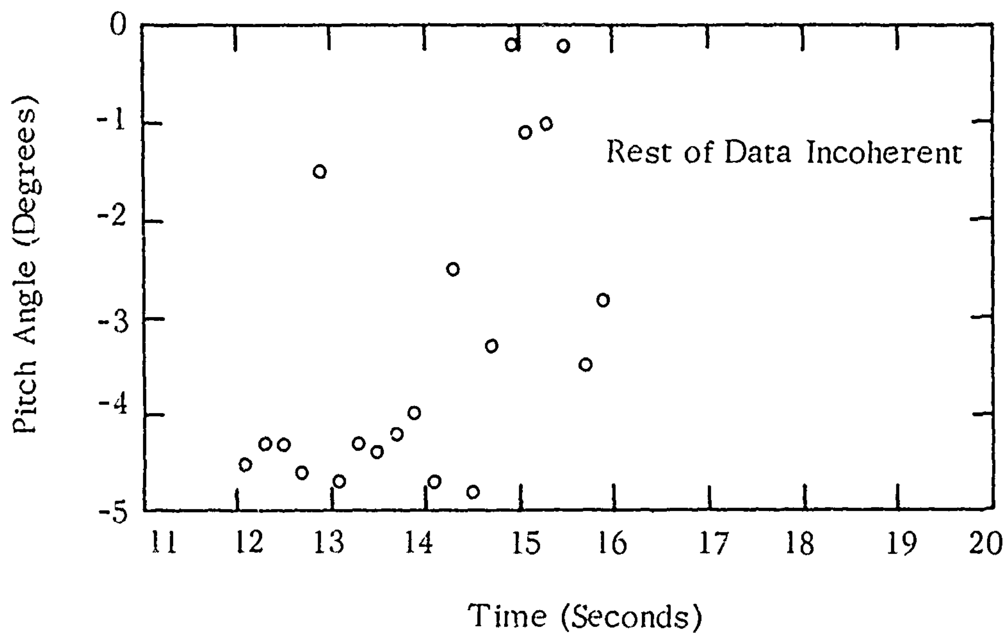



Figure 37. Vane Angle versus Time Run #14.

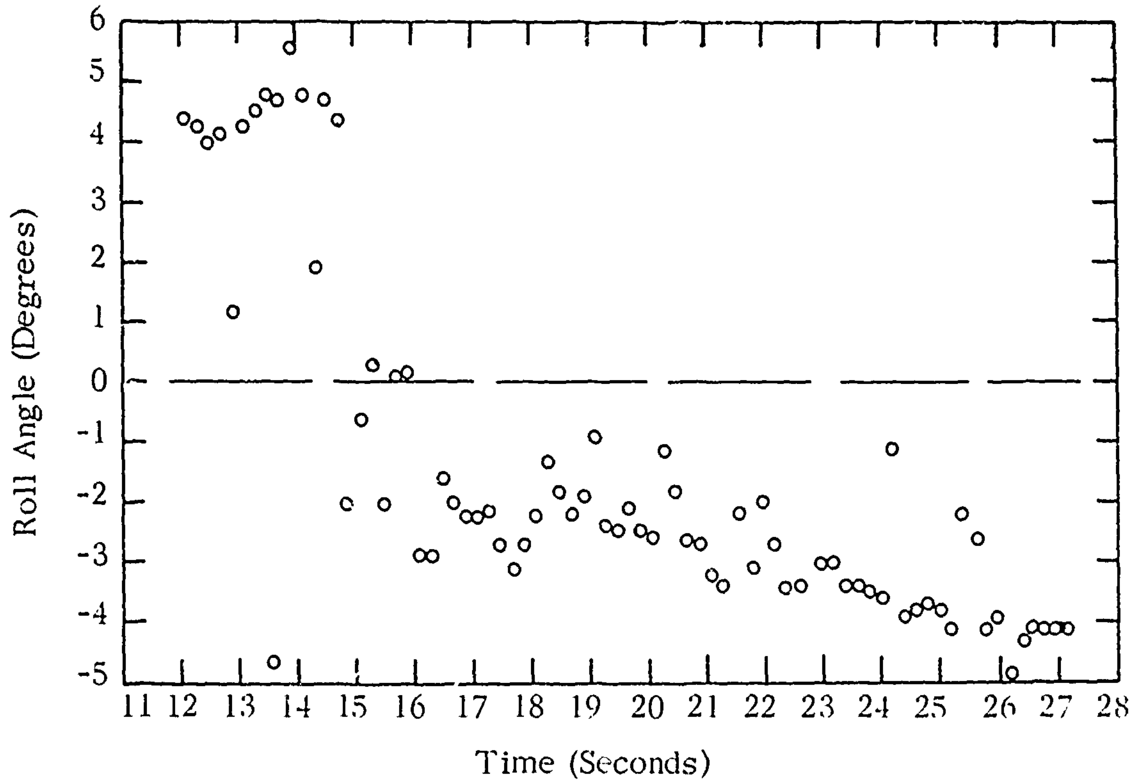



Figure 38. Roll Angle versus Time - Run #14.

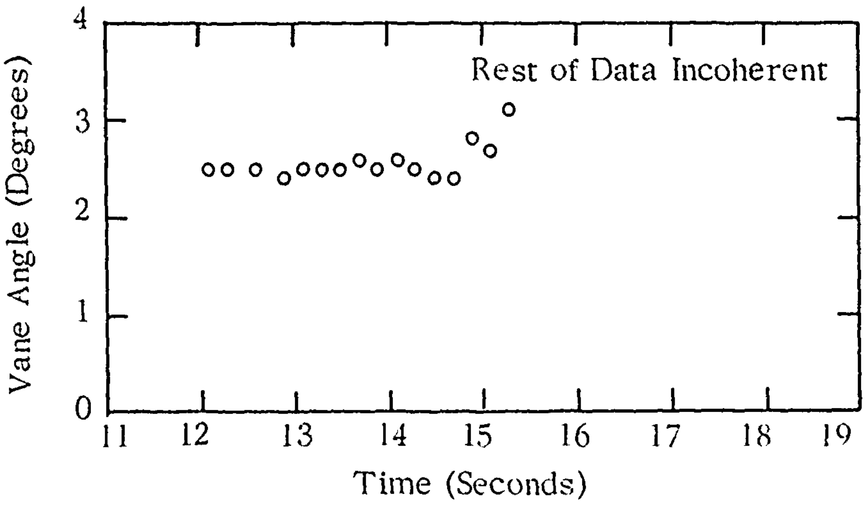



Figure 39. Vane Angle versus Time - Run #14.

Again, using the equation for the restoring moment, $C_{m\alpha}$ was computed with the following results:

| Run | $C_{m\alpha}$ |
|---|---|
| 10 | -2.5 |

## CONCLUSIONS AND RECOMMENDATIONS

The BLU-58/B configuration was statically stable in both the retarded and unretarded flight modes indicated by the fact that for the physical parameters of the bomb and for the flight conditions analyzed, the restoring moment coefficient attained negative values. However, because of the poor quality of the data furnished, no precise conclusion regarding the aerodynamic characteristics of these bombs can be established.

It is recommended that additional free-flight tests be conducted in order to determine the damping and Magnus moments of the BLU-58/B. In addition, a more concerted effort should be made to obtain higher quality data than that furnished for this analysis.

## SECTION III

## SUPERSONIC DYNAMIC WIND TUNNEL TESTING TECHNIQUES

### INTRODUCTION

In recent years several dynamic wind tunnel testing techniques have been developed, including free-flight and constrained angular oscillations.[15-18] While the former exhibits complete six-degrees-of-freedom motion and requires no external support system, certain limitations still exist. The most restrictive aspects of free-flight wind tunnel testing appear to be a lack of initial condition control and the short duration of flight. The constrained angular oscillations technique eliminates these disadvantages: however, the possibility of support interference effects has become evident. In order to simulate free-flight angular conditions in the wind tunnel, control over both duration of flight and initial conditions is necessary. Therefore, all experimental limitations must be carefully considered with respect to the problem being analyzed.

A supersonic dynamic wind tunnel testing technique was developed for fin missiles, the primary objective being to obtain both the restoring and damping moment stability coefficients from a single test.

### AEROBALLISTIC THEORY

For the dynamic one-degree-of-freedom tests of a fin missile, the solution for the angle of attack is given by

$$\alpha = \alpha_T + \alpha_o e^{\lambda t} \cos(\omega t + \delta) \tag{2}$$

where

$$\omega^2 = -\frac{C_{m\alpha} QSd}{I}, \quad \lambda = (C_{mq} + C_{m\dot{\alpha}}) \frac{\rho V Sd^2}{8I}$$

The restoring moment stability coefficient is obtained from

$$C_{m\alpha} = \frac{-2I\,\omega^2}{\rho V^2 Sd} \tag{3}$$

The damping moment stability coefficient is obtained from

$$C_{mq} + C_{m\dot{\alpha}} = \frac{8\,I\,\lambda}{\rho V Sd^2} \tag{4}$$

$\omega$ (rad/sec) is the frequency of oscillation,

$$\lambda \quad (sec^{-1}) = \frac{\ln \alpha_M - \ln \alpha_o}{t_M - t_o}$$

$\alpha_o$ = initial angle of attack

$\alpha_M$ = successive maximum values

$\rho$ = density

S = reference area

d = reference length

I = moment of inertia

Q = dynamic pressure

## TEST SET-UP AND PROCEDURE

Contractor's vertical down-flow wind tunnel of the in-draft type with a continuous flow at Mach 1.3 (Figure 40) was used in the tests.

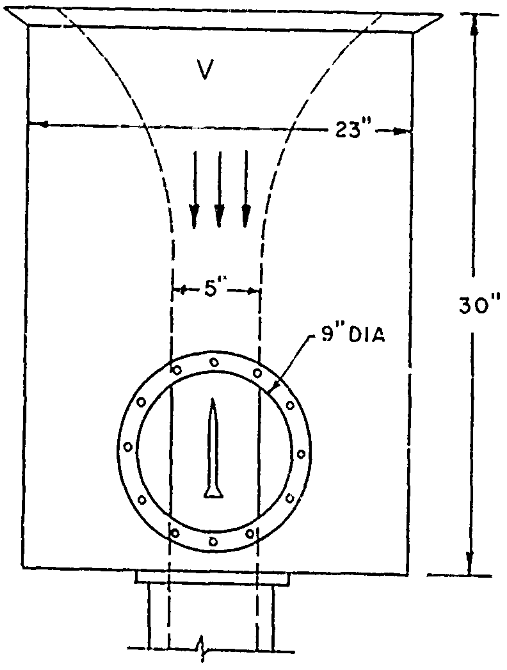



Figure 40. Supersonic Vertical Down-Flow Wind Tunnel.

The supersonic model was a wrap-around fin missile 4.625 inches in length and 0.36 inch in diameter with two center of gravity locations and an interchangeable fin assembly (Figure 41).

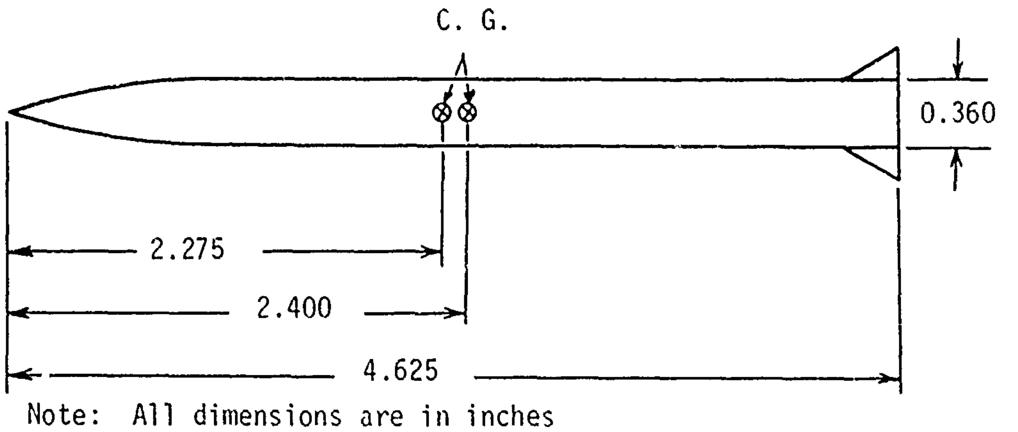



Figure 41. Wrap-Around Fin Missile Model

The model was supported in the wind tunnel test section by a 16 gauge (0.37 inch diameter) spring steel wire through its rear center of gravity and rigidly attached to the tunnel walls. A steel head placed on the wire and firmly secured at the cg of the model prevented translational movements (Figure 42).

The model was constrained in a position 180 degrees to the flow: however, after the tunnel had reached normal operating conditions, the model was released and allowed to oscillate freely. These oscillations were photographed with a Milliken motion picture camera at the rate of 500 frames per second. By utilizing reference marks in the tunnel and on the model, the oscillations were converted to angle of attack time histories (Figure 43).

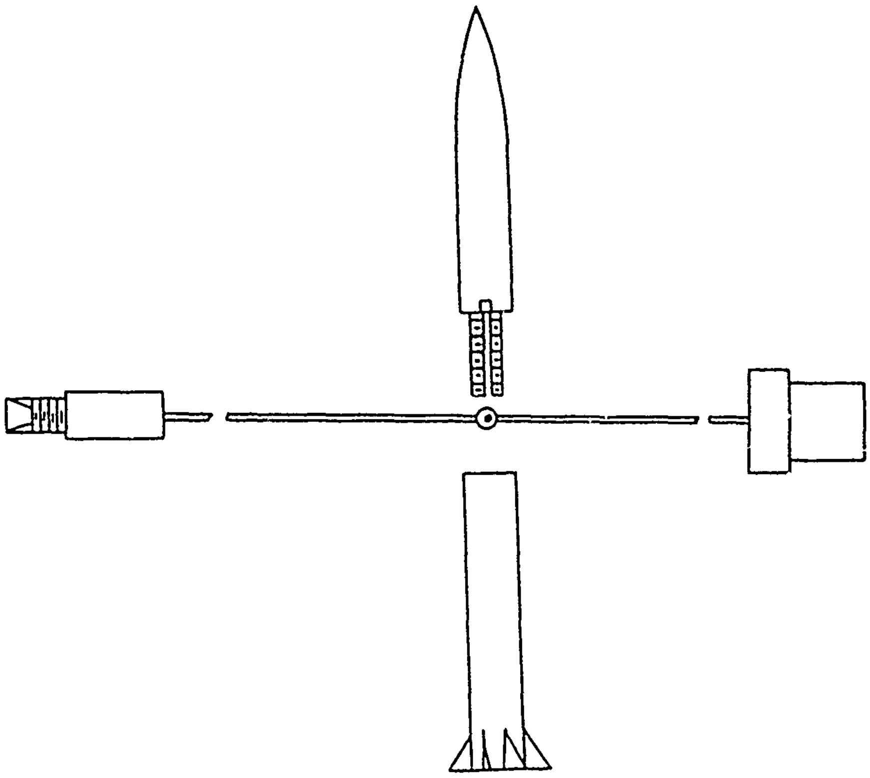


Figure 42. Supersonic Support System.

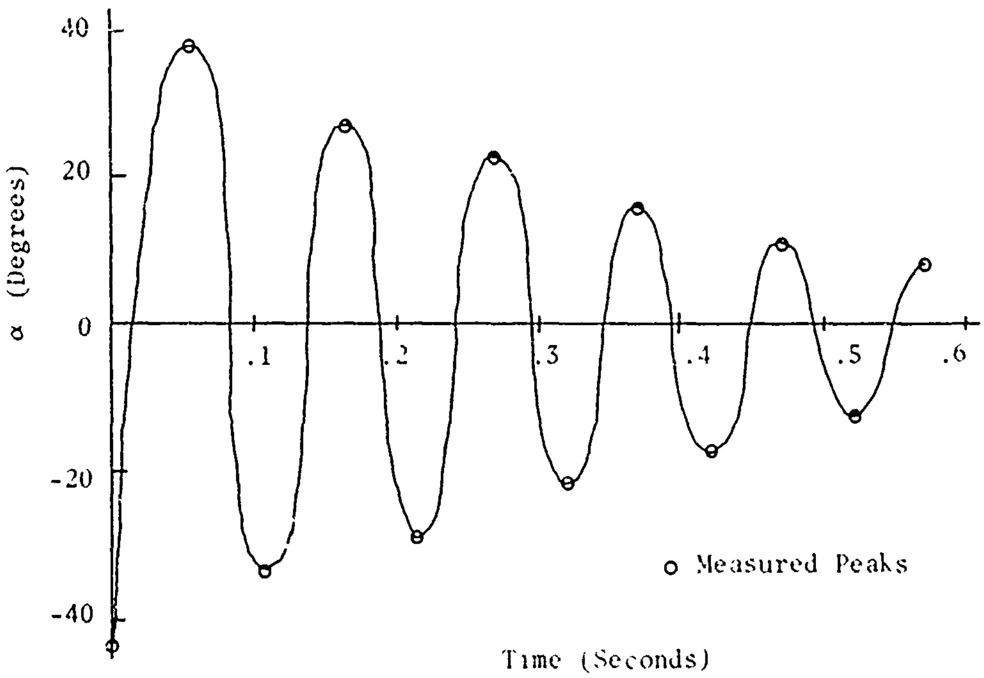



Figure 43. Angle of Attack Versus Time.

## TEST RESULTS

Using the one-degree-of-freedom support system, the model was found to be statically and dynamically stable at all angles of attack ranging from 0 to $\pm$ 90 degrees. The restoring and damping moment stability coefficients resulting from the wind tunnel motions are:

$$C_{m\alpha} = -1.6 \ (\text{rad}^{-1})$$

$$C_{mq} + C_{m\dot{\alpha}} = -602 \ (\text{rad}^{-1})$$

The time required for the angular motion to completely damp out was approximately 0.7 second.

## CONCLUSIONS

The feasibility of the supersonic dynamic wind tunnel testing procedure was proven to yield good results for the fin missile tested. This testing technique has the advantage of furnishing both the restoring and damping moment stability coefficients from a single test.

## REFERENCES


1. Nicolaides, John D.; and Knapp, Charles F., "A Preliminary Study of the Aerodynamic and Flight Performance of the Parafoil," Conference on Aerodynamic Deceleration, University of Minnesota, July 8, 1965.

2. Nicolaides, John D., "On the Discovery and Research of the Parafoil," International Congress on Air Technology, Little Rock, Arkansas, November 1965.

3. Nathe, Gerald A.; Knapp, Charles F.; and Nicolaides, John D., "The Parafoil and Targetry Applications," Target Systems Planning Group, Hill Air Force Base, Ogden, Utah, February 8, 1966.

4. Nathe, Gerald A., "An Analysis of the Parafoil," Southwestern Student AIAA Competition, Graduate Division, Dallas, Texas, April 21, 1966.

5. Nicolaides, John D.; Nathe, Gerald A.; and Knapp, Charles F., "A Summary of the Tests Conducted on the Parafoil," (submitted for presentation at the AIAA Aerodynamic Deceleration Systems Conference, Houston, Texas, September 1966), Aerospace Engineering Department, University of Notre Dame, Notre Dame, Indiana, June 8, 1966.

6. Nicolaides, John D.; and Knapp, Charles F., "Parafoil Design," UNDAS-866 JDN Report prepared for the U. S. Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, Report No. UNDAS-866 (August 1966).

7. Knapp, Charles F.; and Barton, W.R., Controlled Recovery of Payloads at Large Glide Distances, Using the Parafoil, Sandia Laboratory SC-R-67-1049, November 1967.

8. Nicolaides, John D., "Parafoil Performance in Tethered, Gliding, and Towed Flight," Aerospace Engineering Department, University of Notre Dame, Notre Dame, Indiana, October 1969.

9. Nicolaides, John D., Parafoil Wind Tunnel Tests, Aerospace Engineering Department, University of Notre Dame, Notre Dame, Indiana, November 1969.

10. Nicolaides, John D.; and Tragarz, M., "Parafoil Flight Performance," presented at the AIAA Aerodynamics Deceleration Systems Conference (AIAA Paper No. 70-1190), Dayton, Ohio, September 1970.

12. Nicolaides, John D., "Improved Aeronautical Efficiency Through Packable Weightless Wings" (AIAA Paper No. 70-880) presented at the CASI/AIAA meeting in Toronto, Canada, July 1970.

12. Nicolaides, John D.; Speelman, Ralph J.; and Menard, George C., "A Review of Parafoil Programs" (AIAA Paper No. 68-968) presented at the AIAA 2nd Aerodynamic Deceleration Conference, El Centro, Calif., September 1968.

13. Poulsen, N.R., Contractor Support Test of BLU-58/B Supersonic Bomb, ADTC-TR-69-169, Armament Development and Test Center, Eglin Air Force Base, Florida.

14. Nicolaides, John D., Free-Flight Dynamics, Text, Aerospace and Mechanical Engineering, University of Notre Dame, Notre Dame, Indiana, 1964.

15. Ward, L.K.; and Hodapp, A.E., A Three-Degrees-of-Freedom Dynamic Stability Balance for Use in the VKF Continuous Flow Hypersonic Tunnels (M = 6 through 12), AEDC-TR-68-82, Arnold Engineering Development Center, Arnold Air Force Base, Tennessee, (AD 832200), May 1968.

16. Nicolaides, J.D.; Eikenberry, R.S., Dynamic Wind Tunnel Testing Techniques (AIAA Paper No. 66-752), presented at the Aerodynamic Testing Conference, Los Angeles, California, September 1966.

17. Platou, A.S., "Aerodynamic Data Obtained Using the Wind Tunnel Free-Flight Testing Technique," Transactions of the 3rd Technical Workshop on Dynamic Stability Problems, NASA Ames Research Center, Vol. III, Paper No. 3.

18. Regan, F.J. and Beszterczei, "The Applications of an Automatic Film Reader to the Wind Tunnel Free-Flight Technique," Transactions of the 3rd Technical Workship on Dynamic Stability Problems, Vol. III, Paper No. 4, NASA Ames Research Center.

UNCLASSIFIED

Security Classification

**DOCUMENT CONTROL DATA - R & D**

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

| | |
|---|---|
| 1. ORIGINATING ACTIVITY (Corporate author)<br>Department of Aerospace and Mechanical Engineering<br>University of Notre Dame<br>Notre Dame, Indiana 46556 | 2a. REPORT SECURITY CLASSIFICATION<br>UNCLASSIFIED<br>2b. GROUP<br>--- |

3. REPORT TITLE

TEST AND EVALUATION OF MAGNUS ROTORS AND OTHER BODIES, FLIGHT DYNAMICS DATA REDUCTION AND ANALYSIS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report - 15 January 1970 to 14 January 1971

5. AUTHOR(S) (First name, middle initial, last name)

John D. Nicolaides
Charles W. Ingram

| 6. REPORT DATE | 7a. TOTAL NO OF PAGES | 7b. NO OF REFS |
|---|---|---|
| March 1971 | 53 | 18 |

| | |
|---|---|
| 8a. CONTRACT OR GRANT NO<br>F08635-70-C-0033<br>b. PROJECT NO 670A<br>c. Task No 002<br>Work Unit No 34<br>d. | 9a. ORIGINATOR'S REPORT NUMBER(S)<br><br>9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)<br>AFATL-TR-71-32 |

10. DISTRIBUTION STATEMENT

Distribution limited to U. S. Government agencies only; this report documents tests and evaluation of military munitions; distribution limitation applied March 1971. Other requests for this document must be referred to the Air Force Armament Laboratory (DLRA), Eglin Air Force Base, Florida 32542.

| | |
|---|---|
| 11. SUPPLEMENTARY NOTES<br>Available in DDC | 12. SPONSORING MILITARY ACTIVITY<br>Air Force Armament Laboratory<br>Air Force Systems Command<br>Eglin Air Force Base, Florida 32542 |

13. ABSTRACT

~~This~~ report documents three separate series of tests conducted for the purpose of determining (1) if small Parafoils (4.5 square foot) can be used successfully for delivering bomblet munitions; (2) the aerodynamic characteristics of BLU-58/B high-density, retarded bombs for supersonic carriage and release as a step toward eliminating serious flight instabilities which induce large wobbling motions; and (3) the feasibility of supersonic dynamic wind tunnel testing to obtain both restoring and damping moment stability coefficients from a single test. After extensive testing of three configurations of small Parafoils (single flare, double flare, and triple flare) with various aspect ratios, conclusion was reached that a 4.5-square-foot Parafoil with an aspect ratio of 2.0 could be used successfully for bomblet munitions delivery. The BLU-58/B tests were not conclusive. Even though the results indicated that the bomb was statically stable in both the retarded and unretarded flight modes, due to the poor quality of the data used in the tests, no precise conclusion could be reached with respect to aerodynamic characteristics. A wrap around fin missile was used in the supersonic wind tunnel testing procedure with good results. The technique furnished both restoring and damping moment stability coefficients from a single test.

DD FORM 1 NOV 65 1473

UNCLASSIFIED

Security Classification

| 14 KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Parafoil | | | | | | |
| Wind Tunnel Tests | | | | | | |
| Aerodynamic Coefficients | | | | | | |
| Free-Flight Tests | | | | | | |
| Aspect Ratio | | | | | | |
| Airfoil Section | | | | | | |
| Planform | | | | | | |
| Flare | | | | | | |
| Lift-to-Drag Ratio | | | | | | |
| Bomblet Munitions | | | | | | |
| BLU-58/B | | | | | | |
| Ordnance Weapon Systems | | | | | | |
| Restoring Moment Stability Coefficient | | | | | | |
| Retardation Device | | | | | | |
| Pitch Angle | | | | | | |
| Roll Angle | | | | | | |
| Vane Angle | | | | | | |
| Constrained Angular Oscillations | | | | | | |
| One-Degree-of-Freedom | | | | | | |
| Six-Degrees-of-Freedom | | | | | | |
| Supersonic Fin Missile | | | | | | |
| Angle of Attack | | | | | | |
| Damping Moment Stability Coefficient | | | | | | |